Heart rate variability LF/HF ratio: impact of paced respiration on PSD estimation techniques

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Abstract—Differences between spectral estimation techniques using fast Fourier transform (FFT), autoregressive modelling (AR) and Lomp-Scargle periodogram (LSP) with respect to the impact of metronomic breathing on sympathovagal balance were investigated by calculating heart rate variability frequency domain LF/HF ratio for 25 subjects under paced respiration. All techniques showed a significant increase in LF/HF ratio with rising breathing frequency. Differences in calculated LF/HF at higher breathing frequencies ratio between LSP and FFT as well as LSP and AR may be caused by low-pass effect of resampling used for FFT and AR.

Keywords: heart rate variability, paced respiration, power spectral densiy, sympathovagal balance

I Introduction

The human cardiorespiratory system continuously adapts its regulation parameters to variations of physiological demand which in turn originate from changes of e.g. posture, state of exercise, environmental conditions, or psychological stress in order to maintain a sufficient oxygen supply to the tissue. These mechanisms are reflected by heart rate variability (HRV) and power spectral analysis of HRV can be used to quantify the function and activity of both branches of ANS noninvasively [1].

For traditional short-term HRV measurements, three main spectral components are distinguished [2]: A very low frequency component (VLF: 0–0.04 Hz) associated with slow regulatory mechanisms (e.g. thermoregulation and humoral control), a low frequency component (LF: 0.04–0.15 Hz) reflecting sympathetic and vagal activity and a high frequency component (HF: 0.15–0.4 Hz) reflecting vagal activity. The ratio between LF and HF component of HRV power spectral density (LF/HF) is considered to be a measure of sympathovagal balance. Paced respiration is a well established method for determining the influence of respiration on cardiovascular system but it is still under debate whether or not autonomic regulation of cardiovascular system is altered by this method.

Various methods are used for determining power spectral density of RR-interval time series (RR-tachogram), whereby the most common are spectral estimation techniques by means of Fourier transformation (FFT), autoregressive modelling (AR) and the Lomb-Scargle periodogram (LSP) [3,4].

Therefore we investigated the differences between FFT, AR and LSP spectral estimation techniques on calculating the most common HRV frequency domain parameters (LF, HF and LF/HF ratio) as well as the impact of metronomic breathing to sympathovagal balance under paced respiration.

II Methods

A. Subjects and measurement protocol

25 young, non-smoking healthy volunteers (7 female, age: 25.8 ± 3.3 years, BMI: 23.9 ± 3.7) without any history of cardiovascular or cardiopulmonary disease were studied during a dedicated breathing protocol. The study was approved by the local Ethics Committee and all participants gave their written informed consent.

All subjects underwent 6 different breathing conditions in supine position (head up tilt: 30), each lasting 3 min with breathing rates between 10 and 25 breaths per minute (i.e., 0.167 to 0.417 Hz). After 3 min of rest, where no breathing frequency was prescribed, BF was set to 10 BPM (breaths per minute) and then consecutively increased to 25 BPM with steps of 3 BPM. A computer program, which was shown through a projector, with a rising (falling) progress bar was used to visualize inhaling (exhaling).

B. Data acquisition and processing

Electrocardiogram (ECG) and respiratory flow were obtained using a Draeger Infinity Delta multiparameter monitor. From raw ECG (sample rate 200 Hz) and respiratory flow (sample rate 50 Hz) signal parts with a length of 120 s with least irregular breaths were selected and R-wave times automatically extracted. RR-intervals were linear detrended, visually inspected and supraventricular ectopic beats were manually corrected by linear interpolated data. For traditional spectral analysis regularly sampled RR-intervals are needed. Therefore, cubic spline interpolation with a resampling frequency of 4 Hz was used to obtain even sampled RR-time series.

C. Spectral estimation of HRV parameters

As a measure of sympathovagal balance, LF/HF ratio was calculated using three different spectral estimation methods: non-parametric Fast Fourier transform (FFT) using Welchs modified periodogram, parametric PSD estimation using Yule-Walker autoregressive analysis (AR) and Lomb-Scargle periodogram (LSP). For FFT using Welchs method, data was splitted into eight segments with equal length and an overlap of 50 %. Each segment was windowed with a Hamming window and modified periodogram was calculated for each segment. PSD was finally estimated by averaging over all resulting periodograms. AR power spectral density was estimated by fitting a 16th- order [5] autoregressive model to RR-interval data by minimizing the forward prediction error using least squares method and solving resulting Yule-Walker equations. Contrary to traditional spectral estimation techniques, LSP method estimates PSD directly from unevenly spaced data and data is evaluated only at times that are actually measured and therefore no resampling is required. Lomb normalized periodogram is defined by [3, 4]:

$$P_N(\omega) = \frac{1}{2\sigma^2}\left\{\frac{\left[\sum_{i=1}^{N}(x_i - x)\cos(\omega(t_i - \tau))\right]^2}{\sum_{i=1}^{N}\cos^2(\omega(t_i - \tau))} + \frac{\left[\sum_{i=1}^{N}(x_i - x)\sin(\omega(t_i - \tau))\right]^2}{\sum_{i=1}^{N}\sin^2(\omega(t_i - \tau))}\right\}$$

where x and r2 are the mean and variance of the data and s is defined by the relation:

$$\tan(2\omega\tau) = \frac{\sum_{i=1}^{N}\sin(2\omega t_i)}{\sum_{i=1}^{N}\cos(2\omega t_i)}$$

LF and HF were calculated by integrating over low-frequency (0.04–0.15 Hz) and high-frequency (0.15–0.5 Hz) bands. Against traditional HRV analysis, upper limit of HF component was set to 0.5 Hz to include highest respiration frequency. For comparable measures, each PSD was normalized to total power (0–0.5 Hz) of the periodogram.

The impact of breathing frequency on LF/HF ratio was assessed by repeated measures ANOVA. Paired t tests were used to identify differences between PSD estimation techniques at different breathing frequencies.

III Results

Results of LF/HF ratio calculated using FFT, AR and LSP spectrum estimation at 6 different breathing frequencies is show in Fig. 1. Obviously, LF/HF ratio increases with rising breathing frequency (p \ 0.001). Significant differences between LSP and FFT as well as LSP and AR were observed at 10, 22 and 25 breaths per minute (p \ 0.005).

IV Conclusion

FFT, AR and LSP spectral estimation techniques showed a significant increase in LF/HF ratio with rising breathing frequency. LF/HF ratio was lower at breathing frequencies of 10, 22 and 25 BPM with LSP than FFT and AR. For 10 BPM this finding is mainly due to broader peaks of FFT and AR than LSP. The lower LF/HF ratio calculated using LSP at higher breathing frequencies may be caused by the low- pass effect of resampling used for PSD estimation with FFT and AR rather than physiological phenomena [6].

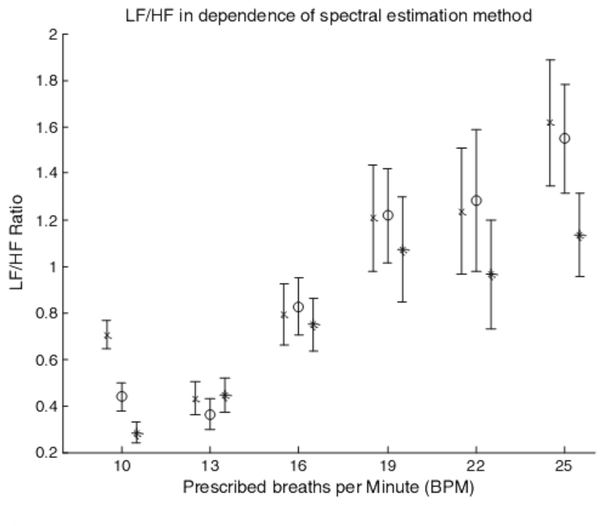

Fig. 1 LF/HF ratio calculated using FFT(x), AR(o) and LSP(*) (mean ± SEM) spectral estimation techniques under paced respiration with breathing frequencies from 10 to 25 breaths per minute

V References

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