Multichannel Spectral Analysis of R-R and Respiratory Series from 24-hour Holter Recordings

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Abstract

The influence of respiration on power spectral analysis of heart rate variability is often ignored. The availability of simultaneous 24-hour recordings of ECG and respiratory activity can provide important information on the possible correlation between the two signals. A spectral multichannel autoregressive method (Nuttall-Strand algorithm) was applied to R-R interval and respiratory time series obtained from 24-hour recordings. Fifteen normal subjects and seven climbers, who reached the altitude of 5000 m, were submitted to the study. The coherence between R-R series and respiration in the LF and HF band was computed and compared in the two groups. As compared to normals, climbers showed a significantly higher coherence in the LF band - possibly because of the presence of periodic breathing.

1. Introduction

Frequency domain analysis of R-R interval time series is widely used to evaluate the autonomic nervous system influence on the heart [1], but the actual contribution of respiration to the R-R spectrum is currently underestimated. A recent review [2] of the literature concerning the influence of respiration on R-R interval power spectra has pointed out that 50% of the studies controlled the respiratory rate, 10% examined tidal volume, and 10% examined both respiratory rate and tidal volume. This review evidences that respiration can influence not only the HF component of the R-R power spectrum, but also the LF are through the respiratory rate and tidal volume [2] [5]. This observation suggests that both ECG and respiratory signal should be recorded for a proper evaluation of the R-R power spectra estimate. Furthermore, the influence of respiration on R-R variability over the 24-hour period has not been deeply investigated. The availability of simultaneous recording of ECG and respiratory activity by Holter technique [6] can provide relevant information on the presence of correlation between the two signals over the 24-hour period. For this purpose, coherence spectrum analysis can be applied to the circadian R-R and respiratory series. In this study, a control group of normal subjects and a group of high altitude climbers underwent 24-hour Holter recording of ECG and respiration. This allowed evaluating the respiratory influence on R-R variability, both normal conditions and in an environment where the respiratory pattern changes dramatically [3].

2. Methods

A group of 15 normal subjects and 7 climbers who reached an altitude of 5000 m (Indian Himalaya) were selected for the study.

For each subject, a 24-hour recording was obtained by a two channel FM Remco-Cardioline recorder, the first channel being the ECG and the second one the respiratory signal as derived by chest positioned piezoelectric transducer (PVDF) [6]. Analog tapes were digitized (at 250 samples/sec) and processed until obtaining 24-hour time series of R-R intervals and of respiration.

Among various methods for multichannel spectral estimation, both parametric and classic, we preferred the parametric method because of the non-deterministic behavior of the input times series; moreover this method produces spectral estimates with accurate frequency resolution even for short time periods.

Nuttall-Strand algorithm was applied to both R-R and respiratory time series for computing the multichannel

AR coefficients. This algorithm allows a spectral estimate with low bias and low variance.

Multichannel parametric spectral estimate should be considered an extension of the single channel case. The following section briefly shows how multichannel AR spectral estimate is obtained.

Let $\mathbf{x}(n)$ denote a vector of samples from a m-channel process at sample index n. A multichannel AR model of order p can be represented by the following equation with the convention that capital bold letters indicate matrices and lower-case bold letters indicate vectors:

$$\mathbf{x}(n) = -\sum_{k=1}^{p} \mathbf{A}(k)\mathbf{x}(n-k) + \mathbf{u}(n)$$

where $\mathbf{A}(k)$ are the m x m autoregressive parameter matrices and $\mathbf{u}(n)$ is the m x 1 vector representing the input driving noise process.

The multichannel AR process may be expressed as:

$$\mathbf{e}_{\mathbf{p}}^{\mathbf{f}}(n) = \mathbf{a}_p \mathbf{x}_p(n)$$

where, indicating with $\mathbf{I}$ the identity matrix:

$$\mathbf{a}_p = \begin{bmatrix} \mathbf{I} & \mathbf{A}_p(1) & \ldots & \mathbf{A}_p(p) \end{bmatrix}$$

and

$$\mathbf{x}_p = \begin{bmatrix} \mathbf{x}(n) \\ . \\ \mathbf{x}(n-p) \end{bmatrix}$$

The driving noise $\mathbf{u}(n)$ is now referenced as $\mathbf{e}_p^f(n)$, where f indicates that it is the forward linear prediction error.

The solution of the equation leads to the equation of Yule Walker for multichannel systems:

$$\mathbf{a}_p \mathbf{R}_p = \begin{bmatrix} \mathbf{P}_p^f & 0 & \ldots & 0 \end{bmatrix}$$

where $\mathbf{R}_p$ is the correlation matrix of the system, $\mathbf{a}_p$ is the AR multichannel model coefficient matrix of p order and $\mathbf{P}_p^f$ is the covariance matrix of the AR driving noise.

Nuttall-Strand's algorithm computes the AR coefficients directly from the data rather than by estimating the normalized partial correlation.

Power spectral density matrix with forward coefficients is obtained by

$$\mathbf{P}_{AR}(f) = T(A(f))^{-1}\mathbf{P}_p^f(A(f))^{-H}$$

where

$$A(f) = \mathbf{I} + \sum_{k=1}^{p} \mathbf{A}(k)\mathbf{e}^{-2\pi j f k T}$$

Once PSD matrix is estimated the coherence function can be calculated. This coherence function is a complex, dimensionless function and for a two channel system it can be expressed by:

$$\Phi(f) = \frac{P_{xy}(f)}{\sqrt{P_{xx}(f)}\sqrt{P_{yy}(f)}}$$

In particular, the magnitude squared coherence, defined as:

$$C(f) = |\Phi(f)|^2 = \frac{|P_{xy}(f)|^2}{P_{xx}(f)P_{yy}(f)}$$

is a function that lies between 0, for frequencies where the two channels are not coherent, and 1, for frequencies where the two channels are perfectly coherent [8][9].

We considered the magnitude squared coherence function, or simply coherence as referred to in the following, because it can be used to measure, as a function of frequency, spectral components present on both time series.

The R-R and respiration series were processed by the Nuttall-Strand algorithm in consecutive 256 data long periods and with a model order 12. Through the AR coefficients the autospectra of both channels and the coherence were computed and displayed on a video screen, using a Compressed Spectral Array (CSA) representation, for visual inspection.

The values of coherence were hourly averaged for selected frequency bands (VLF = .003 - .03 Hz; LF = .03 - .15 Hz; HF = .15 - .4 Hz) [7]. Mean values of coherence for each band were computed for the whole 24-hour period, for the nocturnal and the diurnal period. Coherence was considered significant if greater than .5.

3. Results

As to normal subjects, 24 hour, nocturnal and diurnal mean values of coherence for each frequency band are shown in the table below:

	VLF	LF	HF
24 hour	.36±.05	.40±.05	.66±.11
night	.40±.05	.40±.08	.78±.09
day	.34±.05	.39±.06	.57±14.

Table 1.

The results obtained in the climbers group are shown in Table 2.

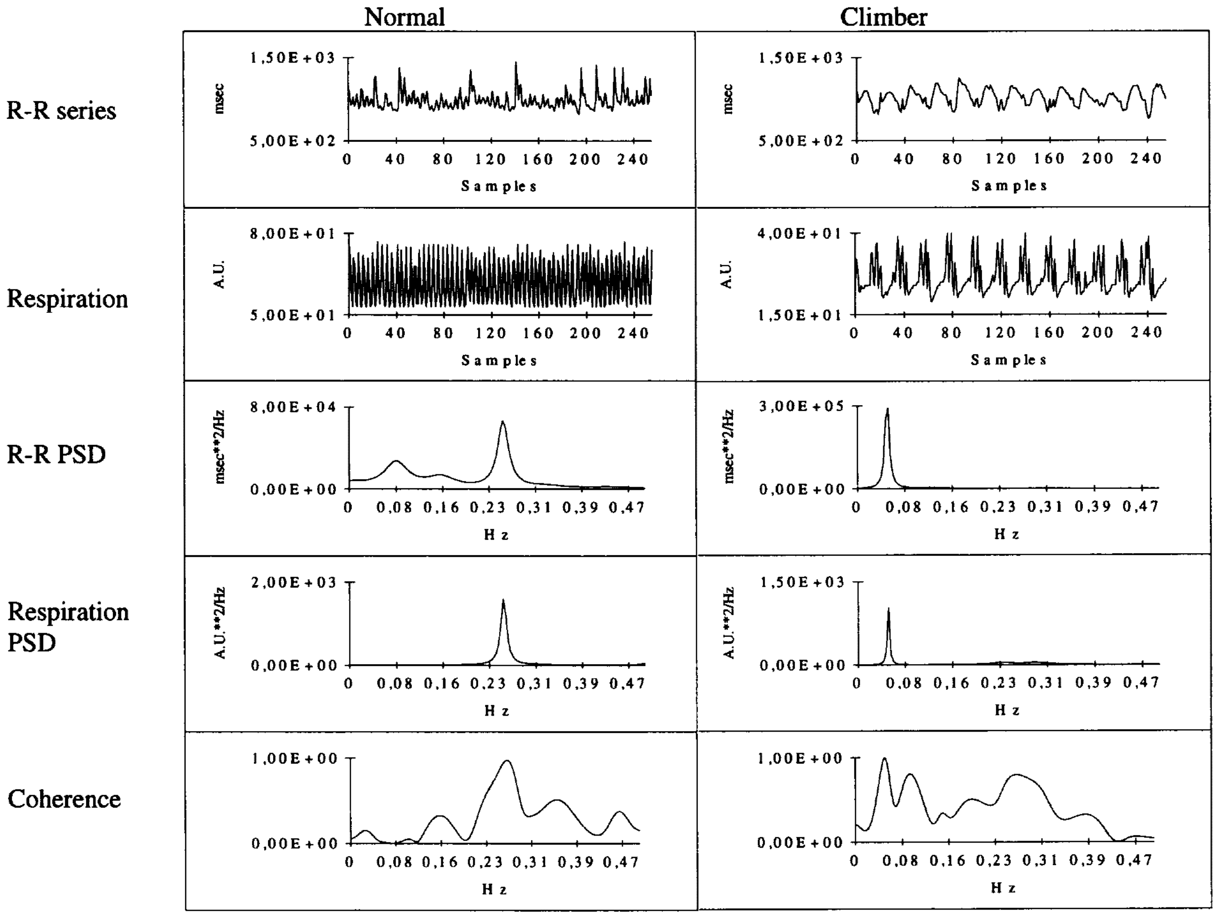

Figure 1. Time series, autospectra and coherence of R-R intervals and respiration in a normal subject and in a climber.

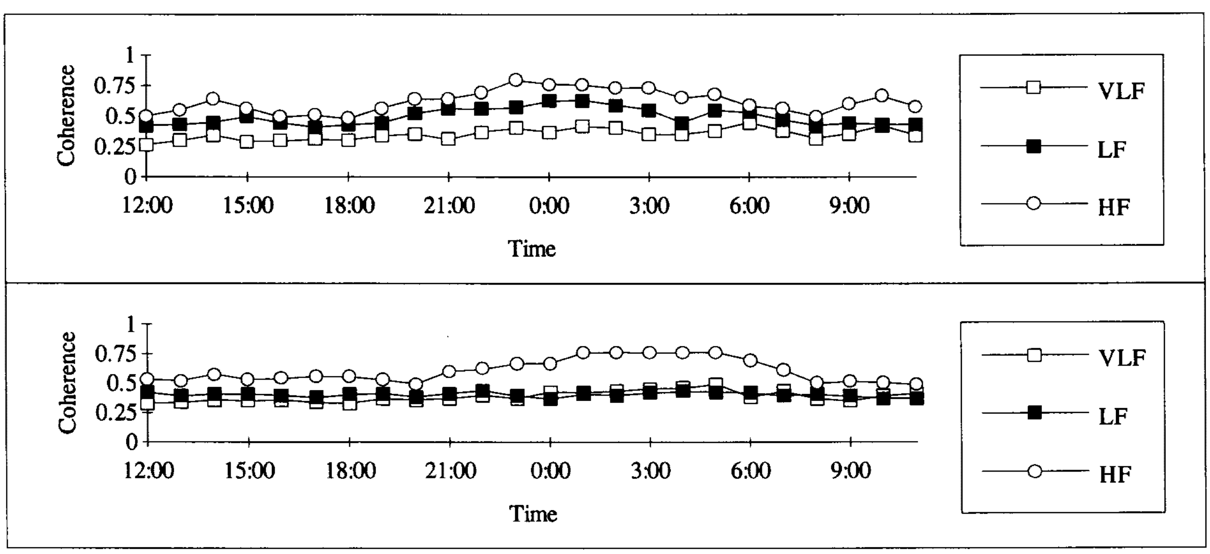

Figure 2. Trends of VLF, LF and HF coherence in climbers (top) and in normal subjects (bottom).

	VLF	LF	HF
24 hour	.34±.02	.51±.08	.62±.08
night	.42±.06	.56±.11	.71±.10
day	.32±.01	.46±.09	.57±.10

Table 2.

The HF coherence pattern was similar to the control one, whereas a significant coherence in the LF band was found at nigh time.

Figure 1 shows two examples of the analysis in a normal subject (left) and in a climber (right). From the visual inspection of the R-R and respiratory series a disturbed breathing pattern is evident in the climber, with periodic apnea and a slow amplitude oscillation of the respiratory signal, possibly related to the coherence in the LF band. As to normal subjects, a clear-cut significant HF coherence peak is present.

Figure 2 refers to the 24-hour behaviour of VLF, LF, HF coherence in the normal (top) and in the climbers' group (bottom).

4. Discussion

As expected, in the control group hourly mean values of coherence between R-R and respiratory autospectra in the HF band were significant during the whole 24 hour period, being higher at night-time. This finding points out that the major contribution of respiration to R-R power spectrum in normals is limited to the HF band.

As concerns the climbers, the coherence was significant in both LF and HF band; the presence of high LF coherence may be related to periodic breathing during the night with a hyperpneic phase related to tachycardia and periodic apnea synchronous with bradycardia. This study is in accordance with the observations of Ichimaru [4], who found a significant relation between R-R and respiration autospectra in normals.

The same respiratory behavior can be expected in many pathophysiological conditions (such as congestive heart failure, and sleep apnea syndrome).

Our findings indicate that the simultaneous recording of ECG and respiratory signal and the possibility of analyzing their coherence may provide useful information for the correct evaluation of the respiratory contribution to LF band, possibly corrupting the baroreflex related oscillations.

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