Available online at www.sciencedirect.com
ScienceDirect
Medical Engineering & Physics 29 (2007) 344–349
Medical Engineering & Physics
www.elsevier.com/locate/medengphy

Heart rate variability in mental stress aloud

Vesna Vuksanović *, Vera Gal

Institute of Biophysics, Faculty of Medicine, University of Belgrade, Višegradska 26/2, 11000 Belgrade, Serbia and Montenegro

Received 18 January 2006; received in revised form 3 April 2006; accepted 9 May 2006

Abstract

Previous investigations on arithmetic stress with verbalization showed that spectral measures of heart rate variability (HRV) did not assess changes in autonomic modulation, although the heart rate (HR) increased. In this study non-linear measures of HRV are determined and linear measures are re-examined in order to understand this apparent discrepancy between HR and HRV changes. In 23 healthy subjects 5-min electrocardiograms (ECGs) were recorded at rest and during arithmetic stress aloud. We determined non-linear (short-term scaling exponent, sensitivity to the initial condition and signal complexity) and linear (low-frequency and high-frequency spectral powers) measures. Our results showed that averaging concealed out an opposite effect of mental stress aloud on spectral measures and that this could be the main reason why the effect was not quantified. We found that increase of HR upon mental stress aloud could be achieved through the decreased as well as increased modulation in high-frequency band (HF). We also showed that non-linear measures distinguished this opposite effect of mental stress aloud on linear measures. Decreased HF power is associated with increase in short-term scaling exponent and decrease in signal complexity, while increased HF power increased sensitivity to the initial conditions. Apart from their opposite response to the mental stress, the two groups differed in baseline in sensitivity to the initial conditions. We suggest that variety of changes in HR dynamics upon different perturbation could be due to some differences in intrinsic properties of the system.

Keywords: Heart rate variability; Nonlinear time series analysis; DFA; Sample entropy; Largest Lyapunov exponent; Mental stress

1. Introduction

Influence of mental stress on heart rate (HR) and spectral measures of heart rate variability (HRV) has been well documented [1]. It has been reported that various types of mental stresses performed in laboratory conditions increase HR and decrease HRV [1–3]. The majority of the studies conclude that the reduction in overall variability is induced by the withdrawal of the highly frequent vagal activity [1]. However, in mental stress performed with verbalization an evident increase in HR was not followed by change in HRV [4,5]. The latter was explained by significant influence of altered breathing pattern upon speaking. Yet, it still remains unclear how could HR change without appropriate and assessable change in its autonomic modulation reflected on spectral characteristics of HRV. If there is a superposition of various effects these effects should be quantified.

Non-linear analysis methods of HRV have been developed to quantify its characteristics that cannot be distinguished by linear methods. Some of them are able to distinguish groups that do not differ in spectral measures [6,7]. The difference between subjects with major depression and control is in “the sensitive dependence on initial condition”, quantified by the largest Lyapunov exponent [6], although the groups do not differ in spectral measures. The advantage of non-linear measures was reported in a follow-up study on various HRV measures in patients with coronary artery diseases. Short-term scaling exponent and approximate entropy change significantly during follow-up, while spectral measures do not [7]. The main observation of these studies is that non-linear measures are more sensitive than linear in detecting subtle changes in intrinsic properties of HR dynamics. Moreover, the nature of the non-linear measures is to quantify qualitative (non-linear interactions between regulatory

* Corresponding author. Tel.: +381 11 3615767.
E-mail address: vvesna@eunet.yu (V. Vuksanović).

1350-4533/$ – see front matter © 2006 Published by Elsevier Ltd on behalf of IPEM.
doi:10.1016/j.medengphy.2006.05.011

mechanisms) rather than quantitative (time- or frequency-domains) properties of the heart rate dynamics.

For these reasons, in this work we wanted (i) to investigate the possibility to assess changes in autonomic modulation of HR in mental stress aloud by non-linear measures and (ii) to re-examine the reasons for spectral measures' failure in doing that.

2. Subjects

Twenty-three volunteers (10 men and 13 women, mean age 33.6 ± 2.3 years) participated in the study. Ethical Committee of Faculty of Medicine approved the study. Informed consent was obtained from all subjects. Subjects were healthy with no previous symptoms of cardiovascular or any other chronic disorder. Mean value of body mass index was (22.5 ± 0.6) kg/m^2. All subjects were non-smokers and they were advised not to drink any coffeinated beverages in the morning prior to the study.

Experiment was performed in a quiet surrounding between 10 a.m. and 2 p.m. ECGs were taken in supine position, at rest and during arithmetic mental stress. After attachment of the electrodes every subject relaxed for 10 min. Afterwards, 5-min ECG was taken in supine rest during spontaneous breathing. Immediately after, also in supine position, subjects performed arithmetic task for 5 min. Standard procedure of mental arithmetic test was performed [1,4,5]. Briefly, subjects subtracted 17 starting from 1000. They were instructed to subtract as accurate as possible. For a single subtraction time allowed was 5 s and was signalled by a sound. They told the result and after each answer subjects received verbal confirmation ("right" or "wrong"). They continued successive subtracting even when the result was wrong. The subjects did not talk during calculation between verbalization of the answers.

3. Analysis of HRV

3.1. Spectral analysis

A 256 consecutive RR intervals, extracted from the ECGs, all with the sinus rhythm, were used for the analysis. Spectral analysis of RR-interval time series was performed using Origin 5.0 program (Microcal Softwere Inc., Northampton, MA, USA), as previously reported [8]. Fast fourier transform (FFT) was used to transform time series in frequency domain. Sampling interval was 500 ms and Hanning window was used to attenuate leakage effect. Power spectral density was calculated and the powers were integrated in the low-LF; (0.04–0.15) Hz and high-HF; (0.15–0.5) Hz frequency bands for all RR-interval time series. An unequal increase of heart rate is normalized by mean RR-intervals. The coefficients of component variance (CCV) in LF and HF band were calculated. CCV-LF and CCV-HF were calculated as the square root of LF or HF power divided by mean RR.

Table 1
Estimated values of minimum embedding dimension (*d*) of unfiltered and filtered RR-intervals time series

	Baseline ($n = 23$)	Mental stress ($n = 23$)
d	15.83 ± 0.29	15.70 ± 0.29
d(LF)	12.48 ± 0.36	11.74 ± 0.30
d(HF)	13.48 ± 0.34	13.52 ± 0.27

Abbreviations—*d*(LF): minimum embedding dimension of time series filtered in LF band; *d*(HF): time series filtered in HF band.

3.2. Detrended fluctuation analysis

Detrended fluctuation analysis (DFA) method was used to quantify presence or absence of fractal-like correlation properties of the heart period (HP) time series [9]. For DFA, RR-interval time series is divided into equal windows, n. In each window, the data were first integrated and then detrended by subtracting the least-squares linear regression line. The mean square fluctuation of this integrated and detrended time series were measured within the observation windows of various sizes ($4 \leq n \leq 64$) and then plotted against the window size on log–log scale [9]. The scaling exponent α presents the slope of this line. Values of α are from 0 (excluding) to 1.5 (including) and indicate different correlation properties of time series [9]. For $0.5 < \alpha \leq 1$ time series is said to be long-range correlated. (The case of $\alpha = 1$ is a special one and corresponds to the $1/f$ behaviour.) Due to the length of the data series we calculated only short-term scaling exponent (α_1) from 4 to 11 beats.

3.3. Largest Lyapunov exponent

Largest Lyapunov exponent (LLE) was used to estimate the chaotic properties or sensitivity to the initial conditions of RR intervals dynamics. Presence of positive Lyapunov exponent indicates chaotic system sensitive to the initial conditions. (Quasi)periodic signals will have an exponent equal to zero. In order to estimate LLE we used software designed for non-linear data analysis TSTOOL V1.11 according to the following method (described also in our previous work [10]). In short, first step in calculation of LLE is reconstruction of an attractor from a given time series. To reconstruct the attractor, i.e. transform one-dimensional time series into d-dimensional vectors in phase space it was necessary to choose two parameters: time-delay and minimum embedding dimension (d). In our work the lag of 1 was used as most appropriate choice for time-delay. This value was based on previous studies and recommendations for analysis of discrete time series [11]. Minimum embedding dimension determines the number of phase space coordinates sufficient to unfold attractor. We estimated d by Cao's method [12], which is efficient for high-dimensional attractors acquired from time series with small number of data points. Estimated values of d are presented in Table 1 (We have not found any statistically significant difference in d between baseline and mental stress. However, values of d differed between non-filtered and filtered