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Multifractal characterization of blood pressure dynamics: stress-induced phenomena

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Abstract

We investigate the scaling features of blood pressure dynamics in healthy rats by means of the wavelet transform modulus maxima method. We discuss how stress affects the phenomenon of multifractality in the cardiovascular dynamics. Typical reactions to stress are considered, and distinctions in the stress-induced effects for male and female rats are reported.

1. Introduction

Many biological time series are highly nonstationary and inhomogeneous. In particular, nonstationary dynamics represents a typical feature of a cardiovascular system [1]. This nonstationarity can be caused by several reasons. On the one hand, it arises from changes in environmental conditions since various external stimuli, stresses, even simple changes of a body position affect the heart rate and statistical characteristics of the heart activity. As a result, the cardiovascular system may demonstrate long transient processes in the beat-to-beat dynamics. On the other hand, the nonstationarity can vary from healthy to pathological regimes [2], the latter allows to assume that environmental conditions are not the only origin of the discussed phenomena.

Processing of biomedical data is often realized within the framework of the following ideology: It is supposed that short fragments of experimental time series are close enough to stationary signals, and such fragments can be studied by means of traditional techniques of the statistical analysis. The given approach seems to be useful if the nonstationarity is associated only with the low-frequency region of power spectrum with respect to the rhythms of interest from the physiological point of view. Such nonstationarity is treated as a trend and may be simply filtered out from the data [3]. However, the given situation is not always true for real time series. As an example, besides a slow "floating" of the mean value, instantaneous frequencies of various rhythmic components can display complex and irregular fluctuations,

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i.e., effects of nonstationarity may be associated with the higher frequencies as well. An analysis of such time series using traditional statistical or spectral approaches can lead to various misinterpretations of the obtained results.

From the viewpoint of possible applications the attractiveness of a particular technique for signal processing depends on its generality (i.e., its lack of restrictions with respect to the homogeneity and the stationarity of the data series). Among such rather universal (and at the same time effective) tools the detrended fluctuation analysis [4,5] and the wavelet based techniques [6–8] are particularly useful. The given tools have found many successful applications (see, e.g., [9–11]). A potentially promising topic in physiological data analysis was offered by recent studies of Ivanov et al. [12,13]. Using the wavelet based multifractal formalism [8] they have shown that physiological signals under healthy conditions are related to a class of multifractal objects. According to Refs. [12,13], multifractal properties of the heart rate dynamics may differ in health and disease, that is why scaling characteristics of the considered formalism become of interest for classification of a state of biological system.

In the given paper, we discuss how stress affects the features of multifractality in the cardiovascular dynamics. Using experimental recordings of arterial blood pressure (BP) in healthy rats we show that the stress-induced changes of multifractality may be different for male and female organisms. We conclude that stress typically decreases "smoothness" of blood pressure dynamics for male rats and sometimes reduces the degree of multifractality. A multiscale structure of BP signals for females is less sensitive to stresses.

2. Experiments

Experiments were performed on 18 white rats weighting from 250 to 300 g. (10 males and 8 females). Each of them was instrumented with intra-arterial polyethylene catheter for direct blood pressure measurements. Arterial blood pressure was recorded in freely moving rats during 30 min at rest conditions, then during 15 min at stress and during 60 min next day after stress (a recovery process). In our experiments, a model of immobilization stress was considered when a rat has no possibility of freely moving. BP signals were acquired on the PC based multichannel complex PowerLab/400 ML401 using the software Chart 4 (ADInstruments Ltd., Australia). Data was collected with the sampling rate of 500 Hz.

In the course of data preprocessing the "clear" fragments of BP signals were chosen for each stage of experiments (fragments of about 10 min without transient processes and artifacts). Taking the given fragments, a transition from original time series (Fig. 1a) to the so-called point processes was performed, the latter being sequences of time intervals between the local maxima of BP signal (Fig. 1b). Aiming to provide more precise determination of the maxima positions, BP signals were interpolated by splines. The extracted sequences of times represent an analogue of heartbeat intervals of an electrocardiogram. Such sequences were further analyzed to reveal stress-induced changes of their complex multifractal structure.

3. WTMM-method

Numerical analysis performed in our work was based on the wavelet transform modulus maxima (WTMM) method [7]. This is now one of the commonly used approaches to study multiscale structures in complex time series. Since the wavelets represent well localized functions, they are appropriate to the processing of inhomogeneous time series. The attractiveness of using the WTMM method is associated also with the possibility it provides of analyzing a wide range of scales and a broad spectrum of scaling characteristics (from small fluctuations and weak singularities to large fluc-

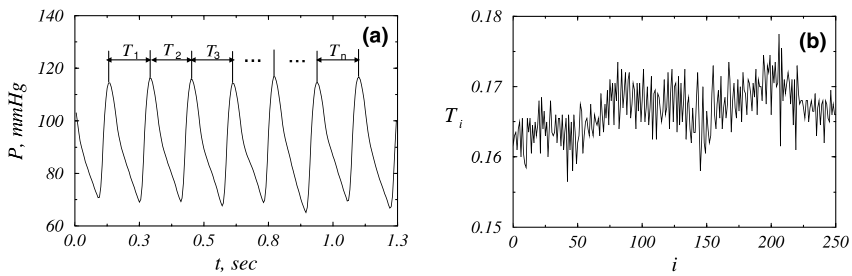

Fig. 1. Blood pressure signal (a) and the sequence of time intervals between the local maxima of the given signal (b).