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Breathing frequency bias in fractal analysis of heart rate variability

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ABSTRACT

Detrended Fluctuation Analysis (DFA) is an algorithm widely used to determine fractal long-range correlations in physiological signals. Its application to heart rate variability (HRV) has proven useful in distinguishing healthy subjects from patients with cardiovascular disease. In this study we examined the effect of respiratory sinus arrhythmia (RSA) on the performance of DFA applied to HRV. Predictions based on a mathematical model were compared with those obtained from a sample of 14 normal subjects at three breathing frequencies: 0.1 Hz, 0.2 Hz and 0.25 Hz. Results revealed that: (1) the periodical properties of RSA produce a change of the correlation exponent in HRV at a scale corresponding to the respiratory period, (2) the short-term DFA exponent is significantly reduced when breathing frequency rises from 0.1 Hz to 0.2 Hz. These findings raise important methodological questions regarding the application of fractal measures to short-term HRV.

1. Introduction

Extraordinary structural and functional complexity is a defining characteristic of living organisms. This complexity gives rise to physiological signals that exhibit interesting properties such as scale invariance and long-term correlations. Statistical physics has only recently began to develop the appropriate mathematical tools to understand and quantify these properties present in a wide variety of biological, physical and social complex systems (Stanley et al., 1996, 1999, 2000).

Generally, signals exhibiting fluctuations whose distribution obeys a power law over a broad range of frequencies are scale invariant and usually referred to as fractal (Mandelbrot, 1983). Fluctuations (F) in these signals can be expressed as a function of the time interval (n) over which they are observed according to the formula:

$$F(n) = pn^{\alpha} \quad (1)$$

where p is a constant of proportionality and α is a scaling exponent that depends on the signal correlation properties. The special case of $\alpha = 1$ is frequently observed in nature and is often called $1/f$ *noise*. Signals exhibiting $1/f$ noise are characteristic of complex dynamical systems, composed of multiple interconnected elements and functioning in far from equilibrium conditions (Bak et al., 1987). These systems demonstrate optimal stability, information transmission, informational storage and computational power (Beggs, 2008). Hence, $1/f$ fluctuations are commonly considered as an indicator of the efficacy and adaptability of the system that produces them (Jensen, 1998).

HRV has been extensively studied by psychophysiologists as an indirect index of autonomic function in health and disease (Camm et al., 1996; Berntson et al., 1997). Common HRV measures include time and frequency domain metrics. Time domain measures calculate the overall variance or the variability between successive interbeat intervals (IBI) using linear statistics. Frequency domain measures assess the variability of the power spectrum in predetermined frequency bands. The rationale for the use of all these different HRV methods in psychophysiological research is to identify and measure characteristic components of heart rate fluctuations that can be associated with specific physiological control mechanisms such as respiratory sinus arrhythmia (RSA) and baroreflex activity (Allen et al., 2007).

The power spectrum of 24-h heart rate records, however, also reveals that the proportion of the signal in different frequency bands is inversely proportional to the frequency over a wide range of scales (Kobayashi and Musha, 1982; Saul et al., 1988). This evidence of fractal $1/f$ noise in heart rate fluctuations may imply that cardiac regulation mechanisms are organized in a critical state that allows maximum adaptability to internal and external stimulation (Stanley et al., 2000). More detailed aspects of this organization can be assessed by algorithms that preserve the temporal information present in the signal. DFA is one of the algorithms that has been widely used to quantify IBI correlation properties as a complementary measure to more traditional HRV indices (Eke et al., 2002; Huikuri et al., 2003). Initial results indicate that healthy HRV is characterized by $1/f$ scaling, while deviations

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