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Scaling and wavelet-based analyses of the long-term heart rate variability of the Eastern Oyster

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Abstract

Characterisations of the long-term behaviour of heart rate variability in humans have emerged in the last few years as promising candidates to become clinically significant tools. We present two different statistical analyses of long-time recordings of the heart rate variation in the Eastern Oyster. The circulatory system of this marine mollusk has important anatomical and physiological dissimilitudes compared to that of humans and it is exposed to dramatically different environmental influences. Our results resemble those previously obtained in humans. This suggests that in spite of the discrepancies, the mechanisms of long-term cardiac control on both systems share a common underlying dynamic.

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1. Introduction

The change with time in the size of the interval between two consecutive heartbeats is called heart rate variability (HRV). There are many (not necessarily independent) sources of HRV in people [1–4], but the variations are largely controlled by the autonomic nervous system through the action of both the sympathetic and the parasympathetic branches, while the main mechanical influences are respiration and blood pressure.

It has been found that long-term HRV shows $1/f$ noise [5]. This behaviour is found in many dynamical systems and draws attention to long-term HRV. The detrended fluctuation analysis (DFA) was introduced by Peng et al. [6] to study the long-range correlations found in HRV [7]. A cross-over was identified around a scale of 10 beats in all healthy subjects, signalling a change of dynamics when going from short to long time scales. Since then DFA has been used to characterise HRV in healthy conditions and in the presence of heart disease [8–13]. Another promising approach is the analysis of HRV using wavelets, which is a mathematical technique specifically suited to analyse non-stationary series. The wavelet transform extracts the cumulative amplitudes of fluctuations of data at each point in time for a given scale [14]. Ivanov et al. [15] presented the cumulative variation amplitude analysis (CVAA), where the inter-beat series were treated with consecutive wavelet and Hilbert transforms and an instantaneous amplitude was assigned to each inter-beat interval. It was found that the same Gamma distribution describes the distributions of instantaneous amplitudes at all scales and for all the healthy subjects in the study. Further studies using wavelets on long-term recordings have explored the possibility to define methods which could be used as markers of heart disease [16–20].

The DFA and CVAA results suggest that there are intrinsic unknown dynamics underlying the long-term behaviour of the healthy human heart. It has been shown by Hausdorff and Peng [21] that it is extremely unlikely that the emergence of these complex patterns is due to having a system of many different independent influences each with their own timescale. The question of the origin of the universal long-term behaviour of HRV remains open.

In this article we present DFA and CVAA studies of long-term HRV in the Eastern Oyster in conditions resembling those of their natural habitat [22]. In Section 1, the circulatory system of the oyster is briefly described. The basic components of the system designed for the monitoring and acquisition of the heartbeat data are also presented. In Section 2, the mathematical principles of DFA and CVAA are reviewed and then applied to the analysis of the oyster's heartbeat data. In Section 3, the conclusions and some general remarks are given.

2. The system under study

2.1. The Eastern Oyster

The Eastern Oyster is a fairly well-studied mollusk [23,24] which lives in coastal waters and lagoons from Canada to Mexico. It has an open circulatory system, i.e.,