

HEART RATE VARIABILITY - A SHAPE ANALYSIS OF LORENZ PLOTS

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Abstract: A new quantitative geometrical method to analyse heart rate variability is presented. The standard image analysis techniques were applied to the grey scale images of Lorenz plots, and the outlines of the attractor areas were determined via a contour following procedure based on a maze walking algorithm. For graphs of simple compact shape, the attractor region contours were described in terms of Fourier coefficients.

Key Words: Heart Rate Variability, Lorenz Plot, Imaging, Attractor Shape

INTRODUCTION

Under normal physiological conditions, heart rate is not a periodic oscillator - the time interval between heart beats is constantly changing due to both the fluctuating inputs to the system and dynamic responses of cardiovascular regulatory mechanisms [1]. Although this heart rate variability has been known about for more than a century, its analysis and interpretation is still an active research field, mainly due to new developments in computational and digital signal-processing techniques, as well as due to new understandings of nonlinear systems [2]. The standard procedure is to deduce the time intervals between R-peaks from measured electrocardiograms. These intervals may be Fourier analysed, but recently, methods of nonlinear dynamics, including the phase space representation, have often been applied [3]. From the heart rate data, a standard Lorenz (or Poincaré) plot is constructed by plotting each RR time interval as a function of the immediately preceding one. These plots give a visual representation of the RR data, but their shapes are also used to classify the data. The shapes of the attractor regions are also determined quantitatively by approximating them by ellipsoids and calculating their principal axes [4]. It was thus of interest to develop a more general method for quantitative representation of the shapes of heart rate attractor regions.

METHODS

Computer programmes were specially developed to convert heart rate data into a grey scale image. They were written in C and run on a Pentium 800 computer with a Linux operating system. Synthetic data were generated by considering the

Gaussian distribution of the RR intervals, while the real data of healthy subjects were recorded for 15 minute intervals on Polar Vantage NV monitors. From the RR time interval data, a standard Lorenz plot was constructed by plotting each RR time interval as a function of the immediately preceding one. All the plots were centred at the average RR value. Data were plotted on a 512x512 array of byte cells where the value in each cell was proportional to the count of graph points corresponding to it. The resulting array was interpreted as an image with 256 grey levels and standard image analysis techniques were applied to it. First, it was normalised to ensure that the full range of 256 values was used, and then smoothed. In the case of very scattered data, the normalisation and smoothing cycle was repeated up to ten times. The image was then binarised by thresholding at half of the maximal height. Beside these standard Lorenz plots, we also considered difference plots. They were constructed in the same way, but the differences between the RR time interval and the preceding one were plotted on the vertical axes.

If the resulting attractor image consisted of a simple compact shape, it was further analysed. In the chosen region of interest a point on the image contour was found. Then a maze walking algorithm was used to determine all the remaining points of the attractor outline [Sevšek, F. and Gomišček, G. Shape determination of attached fluctuating phospholipid vesicles, submitted for publication, 2001]. To describe the resulting attractor shape quantitatively, it was analysed in terms of Fourier coefficients. For this purpose, the contour points were least square fitted to the series of the first ten Fourier coefficients using normal equations and LU matrix decomposition [Sevšek, F. and Gomišček, G. Shape determination of attached fluctuating phospholipid vesicles, submitted for publication, 2001].

RESULTS AND DISCUSSION

The main purpose of this study was to develop a new method to quantitatively characterise the shapes of the heart rate attractor. The method was tested on data from healthy subjects, but a detailed discussion of the experimental procedure is out of scope of this paper, and will be presented elsewhere. The reported procedure proved to be very efficient at describing heart rate variability data. Visual inspection of the resulting images indicated the quality of the recorded data. The ones with multiple regions were mainly related to changing heart rate regimes during the experiment or to recording problems. But most of the standard Lorenz plots were of the well-known club-like shape, centred along the image diagonal. Although Lorenz plots are more generally accepted to represent the heart rate phase space, the difference plots were preferred, since their interpretation was much more straightforward— they reflect typical variations of HR at any given heart rate value. For shape analysis, the difference plots also proved to be more convenient, as they usually consisted of a symmetric

horizontally-extended attractor region. Their shape could be quantitatively determined by the first few Fourier coefficients of the region outline.

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