Evaluation of Heart Rate Variability Using Recurrence Analysis

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Abstract. *This paper presents a new method of evaluating heart rate variability based on nonlinear analysis. We can describe selected processes generated in living organism much more effectively using specific methods of nonlinear analysis. The main tool of recurrence analysis is represented by recurrence plots which visualise the recurrence behaviour of the phase space trajectory of dynamical systems.*

Keywords: recurrence analysis, recurrence plot, nonlinear analysis, heart rate variability,

Introduction

Heart rate variability shows heart's ability to adapt to changing circumstances. The clinical significance of HRV has been known for many years. HRV is, for example, a strong and independent instrument for the prediction of mortality from acute myocardial infarction in cardiology [1]. HRV provides information on the activities of the autonomic nervous system in neurology.

Evaluation of HRV is currently based on time domain or frequency analysis. To obtain complex information about HRV it is necessary to know the results of both these methods. There is an increasing importance of nonlinear analysis of biological data in the last few years. Recurrence analysis - the subject of this study - is one of these techniques. In biomedicine, recurrence analysis was initially used in special cases. However, recent studies [2, 3, 4, 5] suggest possibilities of wider application of recurrent analysis of biological data.

Recurrence plots (RP) - the basic instrument of recurrence analysis allow visualization of phase space trajectories using two-dimensional graph. RPs allow analysis of multidimensional systems. RP can be used to detect transitions between different states or to find interrelations between several systems [6, 7].

The structures created in RP represent the basis for so-called recurrence quantification analysis (RQA). It is a set of parameters introduced by Zbilut and Webber [7] for the possibility of quantitative evaluations of RP. The parameters are based on diagonal lines of the structures of RP [6, 7]. Compared to other traditional methods of nonlinear analysis, a great advantage of RQA is its ability to capture the chaotic properties without a need of a long data series and the fact that it is relatively immune to noise and nonstationarity. RQA is a sensitive tool for detecting any dynamic changes, but it can be easily affected by settings. One of the critical parameters of RQA is the threshold distance ε_i. Even a small change of ε_i can dramatically affect the results of RQA [3, 4]. Currently, we meet with various studies and articles dealing with the choice of threshold distance ε_i [4, 5, 8].
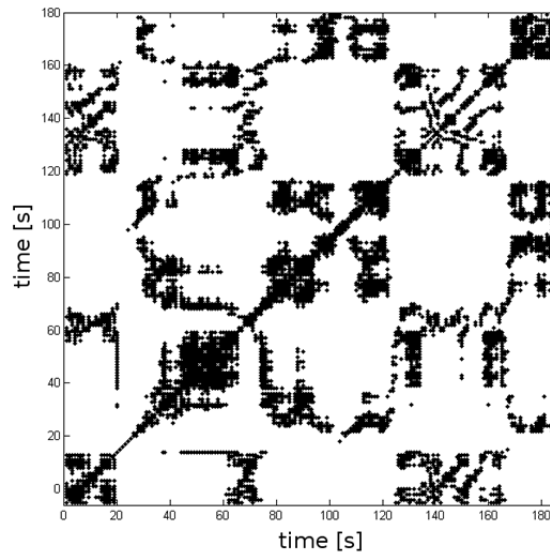
Fig. 1. A representative example of the recurrence plot.

Subject and Methods

In cooperation with the Neurological Clinic of the Motol hospital, we used recurrence analysis for the evaluation of heart rate variability in both patients and healthy subjects. The length of RR intervals measured during the orthostatic test was used as input signal. The main data set for the analysis was patients' data from the clinic. The most commonly represented diseases were neuropathy (CMT), complex regional pain syndrome (CRPS), phobic postural vertigo (FPV) and the conditions of collapse (PRE-COLL). Pre-collapse state is intolerance while standing, without finished collapsing with impaired consciousness, usually in patients with vagotonus standing. The control group consisted of healthy subjects who underwent a clinical orthostatic test. Orthostatic load is carried by the adjustment of the human body from a lying to standing. The load causes stagnation of blood in legs, thus reducing venous return and cardiac stroke volume. In response, heart rate increases, peripheral vasoconstriction occurs and cardiac blood volume and blood pressure equalize in healthy humans.

For the analysis we used a script created in MATLAB. The input parameters are the time delay τ, the dimension m and threshold p. The threshold distance is determined by the percentage of each record so that

$$\epsilon = \frac{S_{max} - S_{min}}{100} \cdot p \qquad (1)$$

where
ε the threshold value,
S_{max} the maximum in the matrix,
S_{min} the minimum in the matrix,
p   an input parameter threshold.

The calculated parameters of RQA were processed in a form of boxplot graphs. Two-sided t-tests were then calculated for selected graphs.

Results

We found significantly higher percentage of recurrent points from RQA measurement in patient with CMT and FPV compared with control group. RQA measurement based on diagonal lines showed significantly higher percentage of points forming diagonal lines (the

value of DET parameter - determinism), in group with CRPS and PRE-COLL compared on the control group.

RQA measurement based on vertical lines showed significant difference in longest vertical line MAXV between PRE-COLL and control group. The last parameter which showed significant difference was entropy ENTR. The values of ENTR were significantly higher in CMT and PRE-COLL groups compared to the control group. Unfortunately, there was no significant difference among individual groups with diseases. In other words, the only differences we found were just between the groups with diseases and the control group.
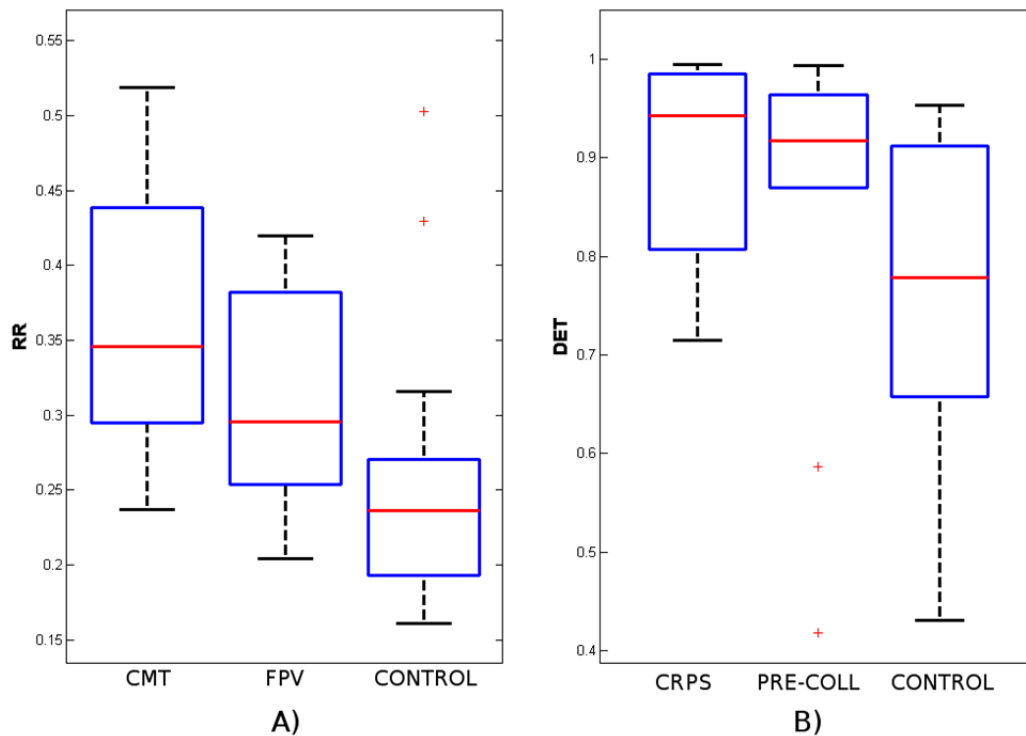

Fig. 2.   A) Box plot illustrating the comparison of percentage of recurrence points (RR) between control group and FPV (P=0.025) and between control group and CMT (P=0.005). B) Box plot illustrating the comparison of percentage of determinism (DET) between control group and PRE-COLL (P=0.005) and between control group and CRPS (P=0.1). Box plot shows interquartile range of values with central line indicates median.

Discussion

The main goal of our study was to verify the possibilities of recurrence analysis in neuroscience. We demonstrated significant differences in the values of RQA parameters for healthy and ill subjects. Higher percentage of recurrence points and higher values of DET, ENTR or MAXV show the changes in HRV, that may indicate pathological conditions.

The main advantage of RPs in comparison to other traditional methods of non-linear analysis is that they can be applied to rather short and even nonstationary time series. RQA is a sensitive tool for detecting any dynamic changes, but can be easily affected by parameter settings. As we mentioned before, one of the critical parameters for the RQA is the threshold distance ε_i. We determine the threshold distance as a percentage. New experiments, however suggest greater accuracy when using the standard deviation method [10] describe above. The next limitation of our pilot study is a small number of patients in the groups. At this time, we are working on new studies, that eliminate these shortcomings and are specifically focused.

Conclusions

We have verified the possibility of using recurrence analysis for the evaluation of heart rate variability. The RQA parameters can be used together with commonly used parameters of HRV to evaluate the heart rate variability in neuroscience. The main RQA parameters suitable for the evaluation of HRV are recurrence rate (RR), determinism (DET), entropy (ENTR) and longest vertical line (MAXV).

Acknowledgements

References

[1] Malik M. Heart rate variability – Standards of measurement, physiological interpretation, and clinical use. Task Force of The European Society of Cardiology and The North American Society of Pacing and Electrophysiology (Membership of the Task Force listed in the Appendix). *European Heart Journal*, Vol. 17, March 1996, pp. 354- 381

[2] Ding H., Crozier S., Wilson S. A new heart rate variability analysis method by means of quantifying the variation of nonlinear dynamic patterns. *IEEE transactions on bio-medical engineering.* 2007, 54 (9), s. 1590-1597.

[3] García G.MA., Fernández Ch.M., Ramos C.J. Errors in the estimation of approximate entropy and other recurrence-plot-derived indices due to the finite resolution of RR time series. *IEEE transactions on bio-medical engineering.* 2009, 56 (2), s. 345-351.

[4] Ding H., Crozier S., Wilson S. Optimization of Euclidean distance threshold in the application of recurrence quantification analysis to heart rate variability studies. *Elsevier.* 2008, 38, s. 1457-1467.

[5] Javorka M. et al. Recurrences in heart rate dynamics are changed in patients with diabetes mellitus. *Clinical Physiology and Functional Imaging.* 2008, 28, s. 326-331.

[6] Traut M. MATLAB® Recipes for Earth Sciences. Potsdam: Springer, 2007. 288s. ISBN 978-3-540-72748-4.

[7] Marwan N. Encounters with neighbours: current developments of concepts based on recurrence plots and their applications. Potsdam, 2003. 331 s. Dizertační práce. University of Potsdam. Dostupné z WWW: < http://www.recurrence-plot.tk/furtherreading.php >. ISBN 3000123474, 9783000123474.

[8] Schinkel, Stefan; Dimigen, Olaf; Marwan, Norbert. Selection of recurrence threshold for sigal detection. *European Physical Journal: Special Topics.* 2008, 164, s. 45-53.