Analysis of Slope Based Heart Rate Asymmetry using Poincaré Plots

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Abstract

Heart rate asymmetry (HRA) is considered as a physiological phenomenon seen in heart rates of healthy subjects. In this article, we propose a novel heart rate asymmetry index and assess the discriminative power of proposed index in comparison with conventional heart rate asymmetry indices. As an illustrative example we discriminate patients suffering from congestive heart failure (CHF) from a healthy (normal sinus rhythm (NSR) group using HRA of beat-to-beat time series. We evaluate the discriminative power of individual features (p<0.01 is considered statistically significant) and area under Receiver Operating Characteristic (ROC) curve. These comparisons show that proposed HRA index is superior feature to conventional HRA index for differentiating NSR from CHF subjects.

1. Introduction

Heart rate variability (HRV) is the variation of the period between consecutive heart beats over the time and is thought to reflect the heart's adaptability to adapt to changing circumstances. Poincaré plot analysis is one of the popular techniques largely used by the researchers for both qualitative and quantitative analysis of HRV signal. The Poincaré plot of HRV signal is constructed by plotting consecutive points of RR interval time series (i.e., lag-1 plot). The line of identity (x=y) in the Poincaré plot is used as the reference to visualize such asymmetry.

Intuitively, asymmetry refers to the lack of symmetry i.e, the distribution of the signal is imbalanced and/or disproportionate [1]. Heart rate asymmetry (HRA) was initially described as a visible phenomenon, mostly present in healthy subjects, which can be assessed by visual inspection using Poincaré plot [2]. HRA is the measurement of time irreversibility of the HRV time series, which is the system level illustration of the complex interaction of control loops of the cardiovascular system and its nonlinear response to perturbations [3-7]. Poincaré plot facilitates the visualization and quantification of HRA [5-7]. Conventional and popular HRA indices defined based on Poincaré plot of RR intervals are Guzkik's index (GI), Porta's Index (PI).

In this study, we have proposed a novel HRA index which is defined using points of Poincaré plot and compared the performance of proposed index with conventional HRA indices. The performance is defined as the distinguishing capability of the parameter between normal sinus rhythm (NSR) and congestive heart failure (CHF) subjects.

2. Data and methods

2.1. Existing HRA indices

The line of identity ($\mathcal{L}_i$) in Poincaré plot is used as a line of symmetry in defining HRA. However, this only defines the visual symmetry of distribution of points with respect to the line of symmetry and the HRA index is used for quantifying symmetry/asymmetry. Points above, below and on $\mathcal{L}_i$ have the property $\Delta RR>0$, $\Delta RR<0$ and $\Delta RR=0$ respectively, where $\Delta RR=RR_{i+1}-RR_i$ and RR_i represpents the i-th RR interval.

Porta's index *PI* is defined as percentage of the number of Points below $\mathcal{L}_i$ with respect to the total number of points in the Poincare plot which are not on $\mathcal{L}_i$ and can be represented as:

$$PI = \frac{M}{N} \times 100$$

Where, *M* and *N* represents the number of points below $\mathcal{L}_i$ and not on $\mathcal{L}_i$ respectively. For each point (P_i) of Poincare plot the distance from $\mathcal{L}_i$ is represented as D_i^+ if the P_i is above $\mathcal{L}_i$ and D_i^- if the P_i is below $\mathcal{L}_i$ (Figure 1). Guzik's index *GI* is defined as the percentage of the distance by the points above $\mathcal{L}_i$ with respect to the total distance and can be represented as:

$$GI = \frac{\sum_{i=1}^{L} D_i^+}{\sum_{i=1}^{L} D_i^+ + \sum_{i=1}^{M} D_i^-} \times 100$$

Where, *L* and *M* are the number of points above and below $\mathcal{L}_i$ respectively. Figure 1 elaborately depicts the definition of *GI* and *PI*.

2.2. Proposed HRA index (Slope Index)

We have defined a novel HRA index, Slope Index (SI),

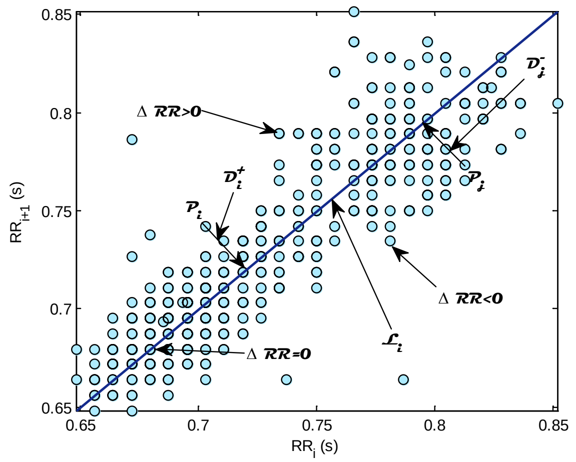

Figure 1. Properties of points in a Poincaré plot used to define and calculate Guzik's Index (GI) and Porta's Index (PI).

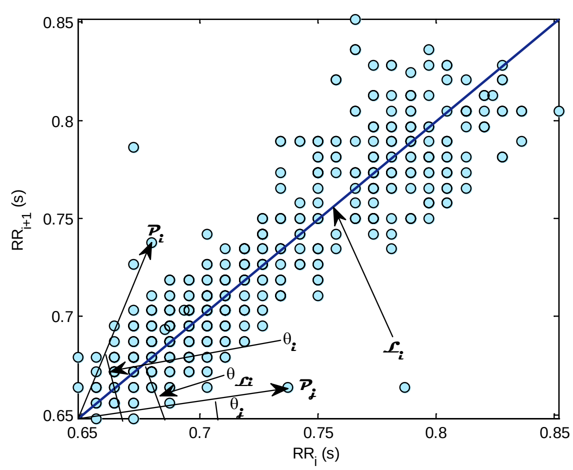

Figure 2. Properties of points (RR_i, RR_{i+1}) in a Poincaré plot used to define and calculate proposed asymmetry index (SI-Slope Index).

based on the slope of the points of Poincare plot (Figure 2). For each point $\mathcal{P}_i$ (RR_i, RR_{i+1}) the slope of the point $\mathcal{S}_i$ is defined as:

$$S_i = \tan(\theta_i) = \frac{RR_{i+1}}{RR_i}$$

For points above, below and on $\mathcal{L}_i$, the range of $\mathcal{S}_i$ are $1<\mathcal{S}_i<\infty$, $0<\mathcal{S}_i<1$ and $\mathcal{S}_i=1$ respectively. Similar to GI and PI, the proposed index SI also calculates asymmetry of the plot with respect to line of identity $\mathcal{L}_i$. The relative slope of each point with respect to line of identity is then calculated as:

$$RS_i = S_{Li} - S_i$$

Where, S_{Li} is slope of $\mathcal{L}_i$. Finally, SI is calculated as the percentage of the relative slope of the points above line of identity with respect to overall relative slope, which is expressed as

$$SI = \frac{\sum_{i=1}^{L} RS_i}{\sum_{i=1}^{N} RS_i} \times 100$$

where, L and N represents the number of points above $\mathcal{L}_i$ and total number of points in the Poincare plot respectively.

2.3. Data

The RR interval series used in this study is obtained from normal sinus rhythm (NSR) and congestive heart failure (CHF) database available at http://www.physionet.org/physiobank/database/#rr. 54 RR interval series of subjects with NSR (30 men, aged 28.5–76, and 24 women, aged 58–73) from Physionet Normal Sinus Rhythm database [8] have been used. The original long-term ECG recordings were digitized at 128 Hz, and the beat annotations were obtained by automated analysis with manual review and correction [8]. In addition, we used 29 long-term ECG recordings of subjects (aged 34 to 79) with CHF (NYHA classes I, II and III) from Physionet Congestive Heart Failure database [8]. Similar to previous recordings, the original long term ECG recordings were digitized at 128 Hz, and the beat annotations were obtained by automated analysis with manual review and correction [8]. More details about the RR interval time series can be found in Bigger et al. [9].

2.4. ROC area and statistics

Receiver-operating curve (ROC) analysis was used [10], with the area under the curve for each feature represented by the ROC area. An ROC area value of 0.5 indicates that the distributions of the features are similar in the two groups with no discriminatory power. Conversely, a ROC area value of 1.0 would mean that the distribution of the features of the two groups do not overlap at all. The area under the ROC curve was approximated numerically using the trapezoidal rules [10] where the larger the ROC area is, the better the discriminatory performance.

The feature values are presented as Mean SD (Standard Deviation) for each group of subjects. The difference between the groups (NSR and CHF) is analyzed using the nonparametric Wilcoxon-Rank Sum test. A p value of <0.05 is considered significant. MATLAB Statistics toolbox is used to perform all statistical operations.

3. Results and discussion

The Mean ± SD values of each HRA index is shown in Table 1. For 30 minutes of HRV signal, only SI is found significantly different ($p<0.05$) among two groups.

Table 1. Mean ± SD values of asymmetry indices for NSR and CHF subjects. * index values are significantly ($p<0.05$) different between groups.

Asymmetry Index	NSR (%) Mean ± SD	CHF (%) Mean ± SD	ROC Area
GI	52.66 ± 3.91	53.59 ± 4.73	0.53
PI	39.69 ± 3.48	37.50 ± 4.27	0.65
SI	48.31 ± 1.56	46.13 ± 2.95	0.78*

Asymmetry index values of each subject of NSR and CHF groups as well as their errorbar are shown in Figure 3. From mean values of all asymmetry indices it is obvious that the NSR subjects are closer to symmetrycity compared to CHF subjects, considering 50 as the reference of symmetricity. Although asymmetry is reported as a phenomenon of healthy physiologic system [6, 7] and the maturation of the autonomic regulation [7], no study has reported increased symmetricity in CHF subjects. Moreover, asymmetricity has been reported in tremor time series of patients with Parkinson's disease [11, 12] and in electroencephalographic seizure recordings [13, 14]. Hence, presence of asymmetry can be

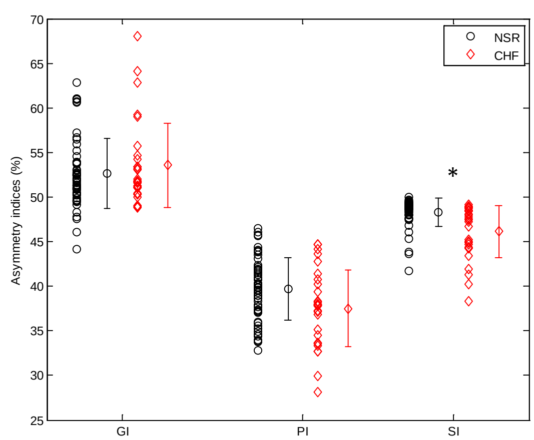

Figure 3. Asymmetry index values of each subject of CHF and NSR groups. Errorbar shows the mean-sd values of each group for each index. * indicates the significant difference between two groups.

an expected phenomenon of healthy physiologic system, but it can be increased or decreased in pathology.

Asymmetry is related with nonlinear dynamics and time irreversibility, which exhibit the most complex interrelationships [1, 3]. Guzik et. al. [7] have reported that the asymmetry in heart rate variability might be related to the response of the baroreflex to increase or decrease the blood pressure [15]. However, exact reason for such asymmetry is largely unknown and remains to be investigated. From the result it is obvious that the proposed asymmetry index (SI) has shown better discriminatory capability than other HRA indices (PI and GI). In this study, the discriminatory capability is measured by the ROC area and it is found maximum for SI (0.78) compared to GI (0.53) and PI (0.65). Therefore, SI is found to be a promising marker that may be used for differentiating pathology from healthy condition.

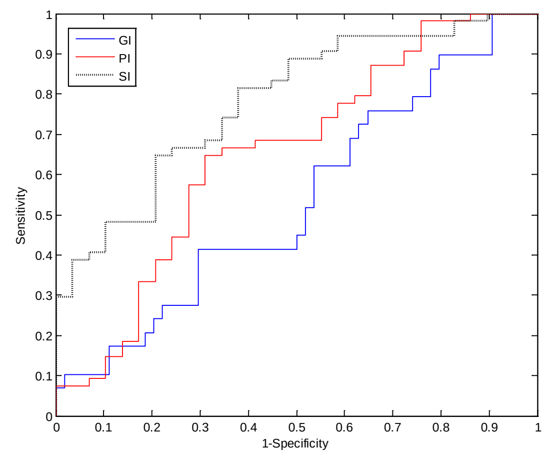

Figure 4. ROC curve of GI, PI and SI. The area under the curve for SI (0.78) is significantly higher than GI (0.53) and PI (0.65).

4. Conclusion

A novel index to measure asymmetry in Poincaré plot is proposed. The proposed index provides an improvement in analyzing asymmetry of the HRV signal. The index SI has been shown to perform better in discriminating congestive heart failure subjects from normal sinus rhythm subjects using short term (30 min) heart rate series. In future, it would be interesting to look at use of proposed index in other pathological condition.

References

[1] Costa MD, Goldberger AL, Peng CK. Broken asymmetry of the human heartbeat: Loss of time irreversibility in aging and disease. Physical Review Letters 2005; 95(19):

[2] Piskorski J, Guzik P. Geometry of the Poincare plot of RR intervals and its asymmetry in healthy adults. Physiological Measurement 2007;28(3): 287-300.

[3] Costa MD, Peng CK, Goldberger AL. Multiscale analysis of heart rate dynamics: Entropy and time irreversibility

measures. Cardiovascular Engineering 2008;8(2):88-93.
[4] Casali KR, Casali AG, Montano N, Irigoyen MC, Macagnan F, Guzzetti S, Porta A. Multiple testing strategy for the detection of temporal irreversibility in stationary time series. Physical Review E. 2008;77(6).
[5] Cammarota C, Rogora E. Time reversal, symbolic series and irreversibility of human heartbeat. Chaos Solitons & Fractals 2007;32(5):1649-54.
[6] Porta A, Casali KR, Casali AG, Gnecchi-Ruscone T, Tobaldini E, Montano N, Lange S, Geue D, Cysarz D, Van Leeuwen P. Temporal asymmetries of short-term heart period variability are linked to autonomic regulation. American Journal of Physiology-Regulatory Integrative and Comparative Physiology 2008;295(2):R550-7.
[7] Guzik P, Piskorski J, Krauze T, Wykretowicz A, Wysocki H. Heart rate asymmetry by Poincare plots of RR intervals. Biomedizinische Technik 2006;51(4):272-5.
[8] Goldberger AL, Amaral LAN, Glass L, Hausdorff JM, Ivanov PC, Mark RG, Mietus JE, Moody GB, Peng CK, Stanley HE. PhysioBank, PhysioToolkit, and PhysioNet - Components of a new research resource for complex physiologic signals. Circulation 2000;101(23):E215-20.
[9] Bigger, JT, Fleiss JL, Steinman RC, Rolnitzky LM, Schneider WJ, Stein PK. Rr Variability in Healthy, Middle-Aged Persons Compared with Patients with Chronic Coronary Heart-Disease or Recent Acute Myocardial-Infarction. Circulation 1995;91(7):1936-43.
[10] Hanley JA, Mcneil BJ. The Meaning and Use of the Area under a Receiver Operating Characteristic (Roc) Curve. Radiology 1982;143(1):29-36.
[11] Edwards R, Beuter A. Using time domain characteristics to discriminate physiologic and Parkinsonian tremors. Journal of Clinical Neurophysiology 2000;17(1):87-100.
[12] Timmer J, Gantert C, Deuschl G, Honerkamp J. Characteristics of Hand Tremor Time-Series. Biological Cybernetics 1993;70(1): 75-80.
[13] vanderHeyden MJ, Diks C, Pijn JPM, Velis DN. Time reversibility of intracranial human EEG recordings in mesial temporal lobe epilepsy. Physics Letters A 1996;216(6):283-8.
[14] Diks C, Vanhouwelingen JC, Takens F, Degoede J. Reversibility as a Criterion for Discriminating Time-Series. Physics Letters A 1995;201(2-3):221-8.
[15] Eckberg DL. Nonliearities of the human carotid baroreceptor-cardiac reflex. Circ Res 1980;47:208–216.

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