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Recurrence quantification analysis of heart rate time series acquired before and after meditation

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Abstract
Cardiac time series show the chaotic behavior. Analyzing the cardiac time series to quantize its periodic nature is a crucial task. Quantizing the periodic nature of heart rate time series in all possible dimension helps in identifying the specific pattern before and after meditation. Fundamental property of non-linear or chaotic system is that at a given sufficient amount of time each state of the system may repeat or may be arbitrarily close to a previously observed state. This is called as recurrence property of a system. Using this property of cardiac time series, Recurrence Quantification Analysis (RQA) is applied to analyze the periodic nature. Cardiac time series of four individuals is acquired before and after meditation. The three parameters obtained after RQA applied over time series, describes the periodic and complex nature of heart rate.

Keywords: meditation, heart rate, periodicity, recurrence quantification analysis, cardiac time series

1. Introduction

Meditation can be defined as both a process and a state. According to the Yoga Sutras, meditation is the act of inward contemplation and the intermediate state between mere attention to an object and complete absorption within it [1]. Some suggest that it can be broadly characterized into two main types namely, concentration and mindfulness meditation [2, 3]. Concentration meditation techniques involve the focusing of attention on a mental _object', for example, counting or monitoring breathing, reciting a mantra or visualizing processes in the body, to still the mind and enhance clarity and awareness. In these forms of meditation, the individual narrows their attentional focus [1].

The heart rate oscillations are transient and highly nonlinear and non-stationary [4], so the analysis of heart rate using Fourier analysis is not possible. Since, Fourier analysis assumes the signal to be stationary, linear and noiseless. To overcome this, Zbilut and Eckmann [5], have introduced a mathematical method which depends on geometrical patterns hidden in heart rate time series. The methods introduced is Recurrence Quantification Analysis (RQA), this finds the hidden relationship like periodicity, randomness and deterministic behavior, without any assumptions.

RQA is used to analyze the heart rate time series before and after yoga. The periodicity is measured in terms of parameters obtained after RQA. RQA deduces four parameters namely: Recurrence Rate, Determinism, Maximal diagonal line and Entropy.

1.1 Related Works

Previous work in RQA is carried out over heart rate variability, impact of tumor in urinary bladder and gait analysis [6]. Peng *et al.* [7] applied Hilbert transform over heart rate time series before and after yoga and obtained spectral analysis. The purpose was to understand the dynamics of heart rate with respect to normal subject. Pallikari *et al.* [8] used average wavelet coefficient method to investigate the scaling features of heart rate variability during meditation, a state of induced mental relaxation. Diosdado *et al.* [9] characterize the complexity of time series by using the degree of multifractality, in particular, heartbeat interval time series. Then observed a loss of multifractality in patients with congestive heart failure, mainly in the sleep phase; we try to explain this loss of multifractality as a loss of complexity produced by the appearance of periodicities in heartbeat interval time series. These periodicities were detected by using the Higuchi's fractal dimension method.

2. Recurrence Quantification Analysis

Heart rate time series show property like periodicity, to explore this RQA is applied. RQA has four parameters namely:

i) *Recurrence Rate (RR):* The more periodic the signal, higher is the *RR* value. Recurrence rate is calculated as in (1).

$$RR(\varepsilon)=\frac{1}{N^2}\sum_{i,j=1}^{N}R_{i,j}(\varepsilon) \qquad (1)$$

ii) *Determinism (DET):* Processes with stochastic behavior (for example random numbers) produce none diagonals or very short diagonals, but periodic signals (for example sine waves) produce very long diagonal lines. Determinism is calculated using (2).

$$DET=\frac{\sum_{l=l_{\min}}^{N} lP^{\varepsilon}(l)}{\sum_{i,j=1}^{N}R_{i,j}(\varepsilon)} \qquad (2)$$

where, l is the length of diagonal line and $P^{\varepsilon}(l)$ is the diagonal line length distribution parallel to the line of identity.

iii) *Maximal diagonal line ($L_{\max}$):* It determines the chaotic behavior of the system. Periodic signals produce long diagonal lines [10]. Maximal diagonal line is estimated using (3).

$$L_{\max}=\max\left(\{l_i; i=1,2,\ldots,N_l\}\right) \qquad (3)$$

where, N_l is the number of diagonal lines parallel to line of identity

iv) *Entropy (ENT):* More the deterministic structure of RP, smaller the number of bits required to represent the structure. Shannon entropy of distribution of diagonal line is calculated as in (4).

$$ENT=-\sum_{l=l_{\min}}^{N}p(l)\ln\left(p(l)\right) \qquad (4)$$

3. Methodology

3.1 Dataset under study

Heart rate time series for four healthy subjects can is obtained from physionet [11]. *Chi meditation group* is considered in this study. There are two time series for each of the four subjects, denoted by record names with the suffix pre for the pre-meditation period and med for the meditation period. Each series is about one hour in duration.

3.2 RQA applied over Heart Rate Time Series

RQA is on each dataset acquired before and after meditation. User adjustable parameters required for RQA are Embedding dimension, Time delay and threshold is obtained from False nearest neighbor method, mutual information and phase space reconstruction method respectively. These three parameters are fed into RQA to obtain four parameters of RQA.

4. Result Analysis

Figure 1 illustrates the heart rate signal before and after meditation. Before meditation it is complex and abrupt. But, after meditation the time series is in same level, i.e it is recurring into same state, thus, exhibiting recurrence property.

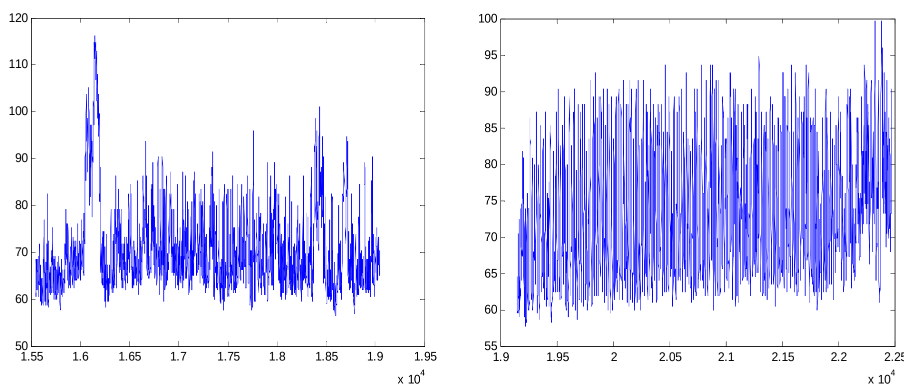

Fig 1: Heart rate time series before and after meditation (horizontal axis: time in seconds, vertical axis: Heart rate

Table 1 depicts the four parameters obtained after RQA. All the parameters show that periodicity was more after meditation. Entropy value show that heart rate before meditation was a complex.

Table 1: Results after Recurrence Quantification Analysis

Subject		Recurrence Rate	Determinism	Maximal diagonal line	Entropy
1	Before	0.0043	2.2628	34	0.6244
	After	0.013	0.5752	55	1.189
2	Before	0.0769	0.8356	83	2.0672
	After	0.0053	0.4924	139	1.0654
3	Before	0.0203	0.6007	158	1.4697
	After	0.0044	0.258	10	0.7362
4	Before	0	0.0008	116	0.002
	After	0.0118	0.5976	128	1.1248

5. Conclusions

Applying RQA over heart rate time series helps in understanding the dynamics and also the periodicity variations after and before meditation. Further improvements can be done in this work, by adding more number of RQA parameters.

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