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USING RQA FOR EVALUATING HEART RATE PATTERNS UNDER CONTROLLED BREATHING

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Abstract: This work study the influence of respiratory control influence on the cardiac rhythm by using Recurrence Quantification Analysis (RQA). Two experiments were performed, such as the variation in the time interval and amplitude of R wave in normal (relaxed) state and performing breathing exercises to improve concentration were investigated. The result is promising and allow to design longer experiments, where the methodology could give better insights of the behavior.

keywords: Time Series Analysis, System Biology, Nonlinear Dynamics and Complex Systems.

1. INTRODUCTION

Biological systems present great deal of complex behavior, such as nonlinearities, time varying nature, discontinuities and a broad range of behavioral characteristics due to personal aspects or disorder of a biological entity of interest. Comprehension of such complex behavior requires the use of observation and analysis. Therefore, tools such as the Recurrence Quantification Analysis (RQA) enables to perform a nonlinear data analysis where behavioral details and patterns may be observed, enabling greater understanding of body functioning in different scenarios, the relationship between stimuli and biological responses and generating breakthrough in the analysis of disease, its causes and consequences.

The analysis of biological signals is of great interest. They not only allow to improve health, but also it affects positively many aspect of life quality. Nonlinear techniques for better understand those systems are receiving increasing attention of researchers. Marwan, *et al.* [1] was able to detect and quantify laminar phases based on heart-rate-variability before a life-threatening cardiac arrhythmia occurred. Acharya, *et al.* [2] by using nonlinear techniques concluded that is possible to effectively detect the presence of coronary artery disease. Lewenstein, Jamrozy, and Leyko [3] reached a 80% success in chronic heart failure detection. Zbilut [4] addresses the importance of noise in determinism. In studies of physiologic mechanism, McCraty and Shaffer [5] and Nardelli *et al.*[6] investigated psychological effects in heartbeat rhythm. In work of Santos *et al.* [7] central tendency measure was used to assess heart rate variability. Marwan N, Zou Y, Wessel N, Riedl M, and Kurths J [8], investigated the asymmetry of couplings between heart rate, mean arterial blood pressure and respiration by using conditional probabilities of recurrence. Finally, Rolink, *et al.* [9] applied RQA to analyze differences between sleep stages and wake using Electrocardiogram (ECG), respiratory effort (RE), heart rate (HR) and the combinations {ECG + RE} and {RE + HR} for sleep analysis.

2. OBJECTIVE

The main objective of this study is to analyze comparatively the response of electrical stimulation of the heart, with regards to the variation in the time interval and amplitude of R wave for a person in normal (relaxed) state and performing breathing exercises to improve concentration. R wave is the first upward deflection after the atrial depolarization and represents early ventricular depolarisation. The analysis is based primarily RQA, also checking the relationship between the change in the time interval and amplitude of the R wave. This work aims to evaluate respiratory control influence on the cardiac rhythm by using RQA.

3. METHODOLOGY

This study evaluates the specific characteristics of a living system by using a recurrence quantification analysis. Comparisons of the ratios diagonal structures reconstruction of recurrence matrix with dimension 1. Determinism and entropy between systems is performed via the recurrence matrix, as well as the average lengths of the diagonals. The systems are also analyzed by observing the change of ECG in time and frequency spectrum and comparison of variation of time histograms between the electrical impulses of the R wave amplitudes and their variations in the two observed stages.

The ECG signals were collected through the potential difference between the region below the left collarbone and the region below the participant's right collarbone in test of 180s long. At one stage the participant was relaxed, breathing in the usual manner (Experiment A), and in a second stage the participants practiced the exercise of inhaling and exhaling, more deeply and slowly at regular cycle (Experiment B).

The signals were acquired at a rate of 2 k samples per second. The collected data was preprocessed by inspection to identify perturbations in the collecting process, such as sampling exclusion criteria. The baseline was observed, and there was no need for adjustments. The data were filtered with FIR filter for the frequency range of the ECG waves, Butterworth, order 250, with cutoff frequency of 150 Hz, the delay generated by the filter was adjusted. Signals were also normalized by the maximum value.

After these procedures, the signals are free from noise, and the signal is considered the biological response, and data collection and pre-processing were performed to minimize the effect of noise and disturbance.

As for specific analyzes, the time intervals between R waves of the EGC signals were identified and the maximum amplitudes of R wave peaks.

4. RESULTS

Consider a data set S of ECG, consisting of N normalized observations, given by

$$S(i), i = 1, \ldots, N \tag{1}$$

The results indicate that the participant ECG signals, Fig. 1, collected in normally relaxed state (Experiment A) have an average variation expressed as relative R wave amplitude of 0.894 and variance 0.020, and the results for the participant making respiratory control (Experiment B), Fig. 2, visually presents a modulation of peaks, with lower global average amplitude, 0.877 and larger variance, 0.081.

The frequency spectrum of the signals in Experiment A presents a well defined peak, while the result for Experiment B gives a frequency spectrum with smaller amplitudes and greater variability in the frequency band.

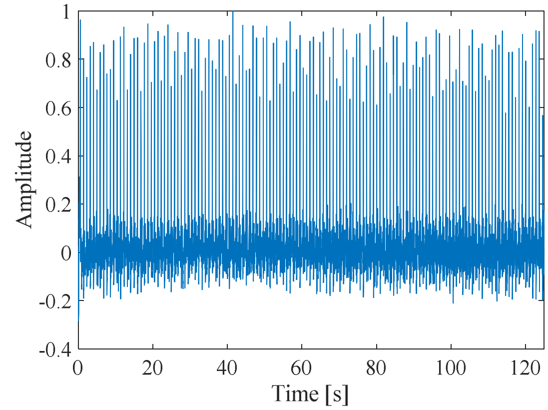


Figure 1 – Electrocardiogram signal in a normal breathing state (Experiment A).

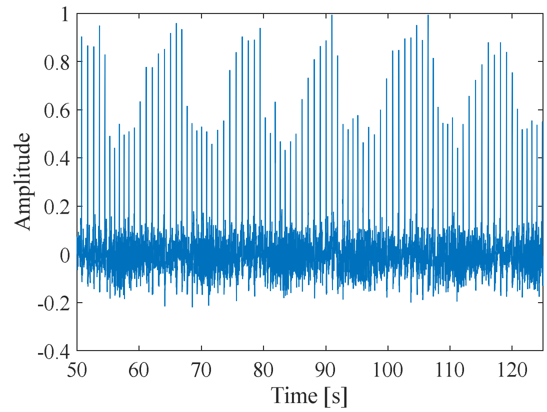


Figure 2 - Electrocardiogram signal in a controlled breathing state (Experiment B).

The intervals between the electrical triggers that stimulate the heart to contract in Experiment A produce average 0.8928; standard deviation 0.0203; kurtosis 3.4635 and skewness -0.1372. Experiment B has average 0.8770; standard deviation 0.0813; kurtosis 1.6749 and skewness –0.1762.

Let us define the distance *M (i,j)* matrix,

$$M(i, j) = \|S(i) - S(j)\|, i = 1,.., N-1; j = 2, \ldots, N \tag{2}$$

where $\|.\|$ is a norm.

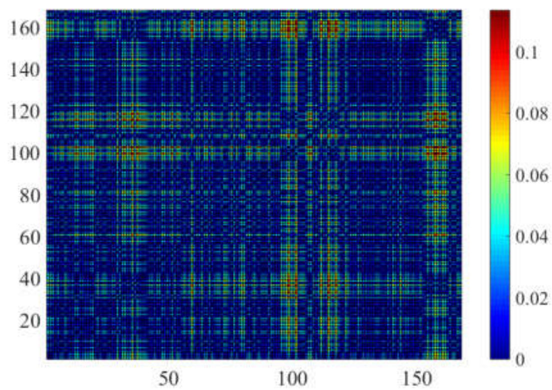
Due to the characteristics of time interval between analyses data of the Experiments A and B, here in all analysis it were used a unitary delay and embedded dimension and a threshold of 0.1.

Experiments A and B were normalized and generated input data sets were visually analyzed with distance matrix. Figures (3)-(4) present the distance matrix where the colors reflect different distances evaluated from Equation (2).

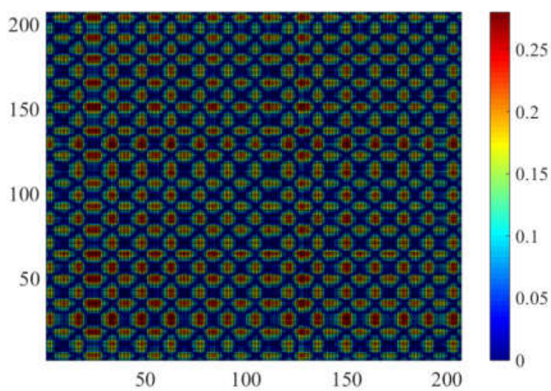
RQA variables were computed to quantify recurrence: DET (determinism), measuring recurrent points forming diagonal line structures; ENTR (information Entropy), a measure of signal complexity and (L) maximum diagonal line length, which inversely scales with the most positive Lyapunov exponents, and therefore with rate at which data trajectories diverge. When not indicated otherwise, the evaluated RQA variables used the CRP toolbox for Matlab® as nonlinear markers of changes in the system under investigation.

It is well known that a normal working heart tend to an uniform pattern, reacting to psychological and physiological stimuli. Without external disturbances, the R wave amplitude and the heartbeat frequency follow opposite trend by increasing when the other one decreases. During controlled respiratory situations, this relationship is better seen since the variable have larger values.

Table 1 shows that the recurrence variables are larger for Experiment B, indicating larger group of recurrence pattern.



(a)



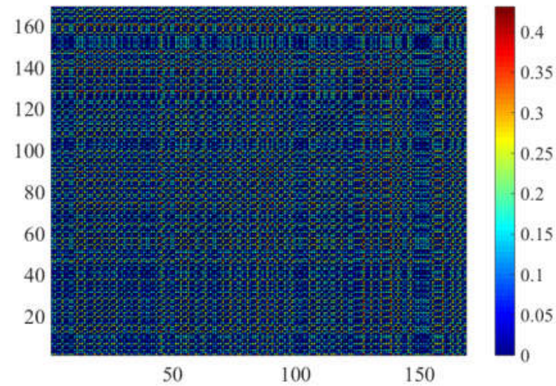
(b)

Fig.3. Distance matrix for time intervals beween R waves of EGC: (a) Experiment A; (b) Experiment B.

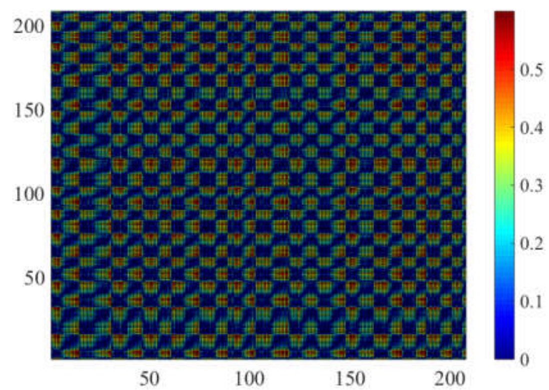
Table 1 RQA variables for Standard breathing (Experiment A) and controlled breathing (Experiment B)

	Amplitude A	Amplitude B	Time Interval A	Time Interval B
DET	0.194	0.343	0.218	0.396
ENTR	0.379	0.698	0.356	0.971
L	2.12	2.30	2.10	2.52

Cross recurrence quantification analysis (CRQA) was evaluated and is presented with embedded dimension varying from 1 to 5 (D=1,...,5), keep other parameters unchanged (Table 2). The Entropy level is larger for Experiment B and increases with the embedded dimension D. This is also true for values of maximum diagonal line length, indicating larger groups with the increase of structural diagonal length.



(a)



(b)

Fig.4. Distance matrix for maximum amplitude of R wave peaks: (a) Experiment A; (b) Experiment B.

Table 2- Time interval R wave cross recurrence amplitude for different values of *D* *(Embedded dimension)*

D	Experiment A			Experiment B		
	DET	ENTR	L	DET	ENTR	L
1	0.245	0.656	2.27	0.628	1.322	2.95
2	0.669	1.364	2.99	0.831	1.782	3.77
3	0.842	1.690	3.56	0.899	2.145	4.88
4	0.898	1.862	3.94	0.944	2.345	5.87
5	0.909	1.941	4.21	0.958	2.532	6.96

5. DISCUSSIONS

Figure (3a) distance matrix shows that the structural diagonal form are less frequent in Experiment A, which also presented a lower amplitude value.

It is known that respiratory control used by athletes to increase physical and mental focus modulates the ECG signal. If the period of time between R waves in the breathing pattern are concentrated around a value for the respiratory control, the time variation occupies a wider range of values in a more uniform fashion, as seen in the

distance matrix presented in section 4. However, using the respiratory control the distance matrix has more grouped structures in a sinusoidal pattern of repetition.
Maximum amplitudes of R wave peaks are less variable for relaxed states when compared with situation with respiratory control, Figure (3b) indicates an increased number of groups when compared to Figure (3a). Therefore, Experiment A might be facing transient changes and the breathing controlled experiment indicates larger pattern group.

6. CONCLUSIONS

The results indicate that the use of RQA is promising in addressing the influence of breathing control to heart rate. It also can also be used in cognitive behavioral therapy where can be taught a person meditation techniques. Distance matrix of amplitude variation highlights an intense variation of low amplitude to the normal state, but for the exercise of respiratory control there is uniform variations, wider and well defined.
The respiratory control responds with significant increase of the indicators based on determinism, entropy and average length of the diagonals. This is likely due to a larger grouping of recurrences.
The cross recurrence between the change of amplitude and time variation showed the same type of behavior that preliminary isolated analysis, larger DET, ENTR and L for the exercise of respiratory control, suggesting the relationship between variation of amplitude and time interval of the excitement the heart. This case study show interesting results that justify its expansion to a larger number of participants, and analysis of other biological aspects within a population.

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