A New Parameter in the Nonlinear Dynamics of the Heart: The Higher Reconstruction Step

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Abstract

Nonlinear dynamics has been playing an outstanding role in the study of heart in the last decades [1-7]. It brought many parameters that improved the diagnostic methods, as the Correlation Dimension [3] or Lyapunov Exponents. In this work we propose a new of these parameters, The Higher Reconstruction Step (HRS), an extension of the Time Lag obtained from the Autocorrelation Function (ACF) [6]. We collected R-R time series from two groups of men: one group with a cardiac chagasic disease (24 individuals) and a second one of healthy people (21 individuals). Typical values of HRS are in the range 1-5, but there are some outliers. After removing the outliers greater than 50 (or greater than 10) the HRS is significantly smaller in the healthy group, with p < 0.01 in a t-test for the supine position.

1. Introduction

The cardiac system is a well known system where we can study some of the Dynamical Diseases [7]. The heart rate variability (HRV) outside its normal limits or the appearance of new rhythms is associated with illness.

This work deals with some modifications in the heart behavior that can be find looking at a new parameter here proposed for the first time, the Higher Reconstruction Step (HRS).

The reconstruction step (or time lag) is used, for instance, to compute one of the fractal dimensions, the Correlation Dimension [2-3].

It is possible to reconstruct the dynamic of a system even if we have just one variable, as was demonstrated by Takens in 1981 [8]. That reconstruction preserves some properties of the original system. The algorithm is based in the construction of m-dimensional vectors starting from the time series, where m is the embedding dimension [6]. Takens´s theorem [8] tells us that there is a representation of the system in a rebuilt space, using $x(t_i)$ as first coordinate, $x(t_{i+\tau})$ as a second coordinate and $x(t_{i+(m-1)\tau})$ as the last coordinate, where τ is the time lag (or reconstruction step).

The main goal of the present work is to evaluate the Higher Reconstruction Step (HRS), an extension of the Time Lag obtained from the Autocorrelation Function (ACF) in order to reconstruct the possible chaotic attractor that lies behind the dynamics.

2. The autocorrelation function

The Autocorrelation Function (ACF) is a mathematical tool used in dynamic to study the stationarity of time series and to produce the time lag used in the Taken´s theorem [6].

Suppose we have a time series $x_1, \ldots, x_N$. The Autocovariance Coefficient at lag **k**, c_k, is defined as:

$$c_k = \frac{1}{N-k} \sum_{t=1}^{N-k} (x_t - \bar{x})(x_{t+k} - \bar{x})$$

Here, $\bar{x}$ is the mean, defined as usual:

$$\bar{x} = \frac{1}{N} \sum_{t=1}^{N} x_t$$

The Autocorrelation Function, ACF(k), is, then, defined as:

$$ACF(k) = \frac{c_k}{c_0}$$

The meaning of the ACF(k) is that it measures if earlier values in the series have some relation to later values [6]. It is important, often, to check if the data at work are independent data and, then, the ACF is used to this check. A plot of the ACF is known as a "correlogram"; in this plot the ACF(k) is the dependent variable and the k is the independent variable.

3. The higher reconstruction step

We define the decorrelation time lag as the smallest value of k that makes ACF(k) < V, where V is usually taken as 0.5 (or 1/e) or the first minimum of ACF(k) [6,12,13]. In this work, we settled the value of V to 0.5.

The point here is that the correlogram depends on the number of points (*n*), as can be seen from fig (1). This implies that the point at which the correlogram crosses the line corresponding to ACF(k) = 0.5 changes together with the number of points, implying a different value for the reconstruction step for each value of *n*. This property allows us, then, to define a new function, the Reconstruction Step Function, RSF(n).

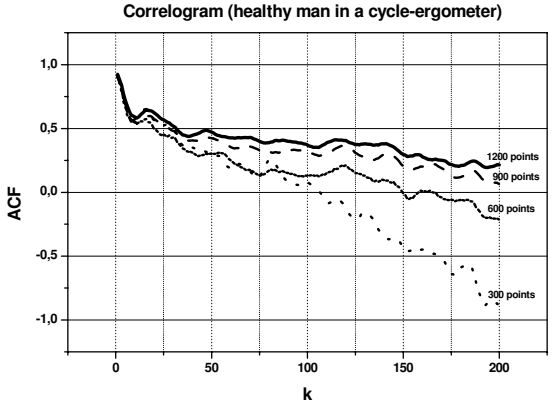

Figure 1. Correlogram for a healthy man in a cycle-ergometer. The curve changes as the number of points changes, implying different decorrelation time lags when the curves cross the line ACF = 0.5.

In this work we explore an specific characteristic of this function, looking at its maximum value, which we called Higher Reconstruction Step", HRS(n), which, obviously, depends on *n*. We called it "the higher" and not "the highest" because we have a limited number of data in each series and we do not know if there could be a higher value if the series was extended.

4. Methods and tools

We collected R-R time series from two groups of men: one group with a cardiac chagasic disease (24 individuals) and a second one of healthy people (21 individuals). The series, for each individual, were collected in two positions: supine and after passive 70 degree head-up tilting, with volunteers seated in a saddle (dismissing the initial transient changes). All the series were collected at the same period of the day, to avoid changes in their standards due to biological rhythms. The variable recorded were the RR intervals (ms), each one lasting for a little more than fifteen minutes. Specific software was used to detect R waves of ECG signals and the respective periods [9-10]; the RR interval were then obtained.

At first, a conventional statistical analysis was done regarding the variability of the RR intervals. All the statistical tests failed in discriminating the two groups (health and chagasic).

Then we computed the HRS. To this end, the time lag is computed as usual, looking for the time lag in an ACF, but the difference is that it is calculated many times, increasing the number of points in the data set used (from a starting value of 300) until the whole time series is swept. As the data set used is increased, new time lags are found, forming a new sequence. The HRS is just the biggest (till that number of points) of them, for each time series.

5. Results and analysis

The values found for the HRS are displayed in table 1.

Table 1. Values of HRS for the two groups

	CHAGASIC		HEALTHY	
	SUPINE (C1)	HEAD UP (C2)	SUPINE (C3)	HEAD UP (C4)
1	5	3	145	4
2	1	1	2	21
3	6	9	3	3
4	2	2	2	3
5	1	1	3	3
6	173	1	2	8
7	4	4	3	3
8	22	36	2	3
9	3	5	15	2
10	3	2	2	2
11	14	1	2	7
12	8	5	2	5
13	4	8	1	2
14	5	5	1	2
15	5	22	2	3
16	55	70	2	3
17	5	2	2	3
18	2	2	1	2
19	5	9	2	2
20	6	18	2	3
21	15	6	2	3
22	6	4		
23	2	25		
24	5	7		

5.1. Analysis

First, we tested all the columns with respect to normality with the Shapiro-Wilk test. The outcome is that we can assume normality for all the columns ($p < 0.001$). In the following, ν represents de number of degrees of freedom.

(a) The t-test for two independent samples (unilateral test for unequal variances) for the columns C1 and C3 (supine position). The t-test produced $p > 0.05$, indicating that there is no statistically significant difference between the two groups.
(b) The same as above performed for the columns C2 and C4 (head up position). It produced $p = 0.036 < 0.05$ ($\nu = 27$), indicating that the values of HRS are bigger for the chagasic group compared with the healthy group.
(c) Tests for paired samples for the chagasic group (columns C1 and C2): the t-test, the Wilcoxon test and the signal test gave $p > 0.05$ (there is no statistically significant difference).
(d) The same for healthy group (columns C3 and C4): there is no statistically significant difference according to the t-test; there is a statistically significant difference according to the Wilcoxon test ($p = 0.049 < 0.05$); there is, also, a statistically significant difference according to the signal test ($p = 0.004 < 0.01$).

Following, we removed the outliers greater than 50. Again, we can assume normality for all the columns ($p < 0.001$).

(a) The t-test for two independent samples (unilateral test for unequal variances) for the columns C1 and C3 (supine position). The t-test produced $p = 0.008 < 0.01$ ($\nu = 34$), indicating that there is a statistically significant difference between the two groups, the values being greater for the chagasic group compared to the healthy group.
(b) The same as above performed for the columns C2 and C4 (head up position). It produced $p = 0.041 < 0.05$ ($\nu = 30$), indicating that the values of HRS are bigger for the chagasic group compared with the healthy group.
(c) Tests for paired samples for the chagasic group (columns C1 and C2): the t-test, the Wilcoxon test and the signal test gave $p > 0.05$ (there is no statistically significant difference).
(d) The same for healthy group (columns C3 and C4): there is no statistically significant difference according to the t-test and to the Wilcoxon test ($p = 0.049 < 0.05$); there is a statistically significant difference according to the signal test ($p = 0.004 < 0.01$), the values for the supine group being bigger than the values for the head up group.

Last, we removed the outliers greater than 10. Again, we can assume normality for all the columns ($p < 0.001$).

(a) The t-test for two independent samples (unilateral test for unequal variances) for the columns C1 and C3 (supine position). The t-test produced $p = 0.001 < 0.01$ ($\nu = 17$), indicating that there is a statistically significant difference between the two groups, the values of HRS being bigger for the chagasic group compared with the healthy group.
(b) The same as above performed for the columns C2 and C4 (head up position). It produced $p > 0.05$ ($\nu = 24$), indicating that there is no statistically significant difference between the two groups.
(c) Tests for paired samples for the chagasic group (columns C1 and C2): the t-test, the Wilcoxon test and the signal test gave $p > 0.05$ (there is no statistically significant difference).
(d) The same for healthy group (columns C3 and C4): there is a statistically significant difference according to the t-test with $p = 0.002 < 0.01$ ($\nu = 17$), but with opposite outcome compared to the previous ones: the values for the head up group being bigger than the values for the supine group.; there is a statistically significant difference according to the Wilcoxon test ($p = 0.004 < 0.01$).

6. Conclusion

The conventional statistical analysis was not able do establish a statistically significant difference ($p>0.05$) between the two groups for all the usual parameters. But the HRS succeeded in doing the task. Considering the groups without the outliers greater than 10 or greater than 50, it was found a statistically significant difference between the two groups in supine position.

There is a lot of work ahead, since we measured the HRS just for one specific disease. The next step is to measure it for other diseases as well as for different states of the individuals belonging to the same category (healthy or with a specific disease).

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