Spectral Analysis of Heart Rate Variability of Holter Records

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Abstract.

The paper discusses spectral methods for analyzing heart rate variability, which is a dynamic, non-stationary variable. Today the analysis of heart rate with mathematical methods is a current task as diseases of the cardiovascular system, and disability and mortality in humans as a result of them are very common worldwide. In our modern age, technologies need to be of assistance to medicine and to help both improve the health of individuals and take appropriate preventive measures to protect the health of people. Electrocardiography and long-term monitoring of Holter are well-established, non-invasive medical methods for cardiovascular activity testing. Spectral analysis of the heart rate variability makes it possible to evaluate the work of the heart and to give an estimate of its condition in the coming days. Spectral analysis of variability is performed in three frequency ranges and can be done with different mathematical methods. This paper uses a Welch periodogram method to analyze records of healthy individuals and patients with arrhythmias. The analysis was performed on real Holter continuous cardiac records on patients with proven cardiac disease, diagnosed by a cardiologist, and on people without cardiovascular problems. The presented numerical and graphical results are obtained using the MATLAB software program, created by the authors. The comparative analyses show differences in the studied frequency parameters between patients with arrhythmia and healthy individuals. The conducted research and the obtained results can be useful in the clinical practice of cardiologists.

Keywords: arrhythmia; cardiovascular system; healthy individuals; mathematical methods; Welch periodogram

1. Introduction

From the analysis of cardiac data, several parameters can be drawn, they are very indicative of the functioning of the human cardiovascular system. The variability in intervals between heart beats, known in the scientific literature as Heart Rate Variability, is an effective characteristic that is obtained in a non-invasive manner and can be used to evaluate and predict the activity of the heart and the overall health of the human body (Acharya et al., 2006).

Spectral analysis of HRV is an indirect way of assessing the influence of the autonomic nervous system on the activity of the human heart and is a means of monitoring the factors (environment, individual's internal state, stress, etc.) affecting the health of individuals. The autonomic nervous system has two parts: the parasympathetic nervous system, which acts when the body is at rest, and the sympathetic nervous system, which regulates the body in motion. The Spectral analysis of HRV is characterized by low frequency variable (LF) and high frequency variable (LF). The ratio of Power in the LF area and the HF area (LF/HF) assesses the sympathetic balance of the human body.

When performing a spectral analysis of 5 minutes HF, typically 2 peaks are observed in power spectra: in low frequency area (0.04-0.15 Hz) and high frequency area (0.15-0.4 Hz) (Kleiger et al., 2005).

Reduced HRV values are a predictor of the risk of death from cardiac problems and after myocardial infarction (Kleiger et al., 2005). The studies must be conducted on the data with good quality of information and a normal sinus rhythm of the time sequence. The ectopic complexes and artifacts must be removed from the interval series, the series of normal intervals (NN intervals) are formed, and mathematical methods of analysis are applied to it.

The cardiac data used for mathematical analysis can be 5 minutes (short term extracted by electrocardiograph) and 24 hours (long term extracted by Holter).

The studies presented in this paper were conducted at Medical University - Varna, Bulgaria with Holter (24 hours records). The analysis was applied to the records obtained by Holter's second channel lead. Two types of individuals were studied: patients with different types of arrhythmias and healthy individuals. The records were made with the help of modern Holters, which were purchased for a research project under the National Science Found, Republic of Bulgaria. The resulting records of healthy and diseased individuals are stored in a created database of cardiology records. All records are accompanied by a diagnosis by a cardiologist.

A cardiovascular disease arrhythmia

Arrhythmias can be associated with different symptoms, but sometimes individuals with heart rhythm disorders can go on without symptoms. The most common symptom is palpitations (unpleasant sensation of cardiac contractions). On the other hand, not all individuals who have palpitations can have an arrhythmia. Often complaints start suddenly; patients report the cardiac arrest, accompanied by anxiety and fear.

In an accelerated heart rate, except heartbeat can be monitored and fatigue, shortness of breath and fatigue. Some of the rhythmic disorders that occur with a very high heart rate can lead to loss of consciousness and are life-threatening. Often, no complaints are accompanying slow heart activity. Fatigue, dizziness, and more pronounced bradycardia may be observed, which may start suddenly, and there may also be loss of consciousness.

Ventricular tachycardia is a common heart rhythm disorder caused by abnormal signals in the lower chambers of the heart. This is an arrhythmia that results in a series of three or more ventricular complexes with a frequency of 100-250 beats/minute.

A premature ventricular contraction (PVC) is a common type of ventricular arrhythmia. In this arrhythmia, the heartbeat is caused by the ventricles (the so-called Purkinje fibers in them), not by the sinoatrial node. PVC produces a heartbeat that occurs long before the time when a normal sinus rhythm usually occurs. This arrhythmia causes interruption of normal heart activity originating from the sinus node. When an individual was diagnosed with a heart condition, then this arrhythmia can be dangerous for the subject (Arrais et al., 2018).

2. Literature Review

HRV analysis methods have been established in the scientific literature and used in the development of software systems for the analysis of HRV data.

The use of mathematical transformations by which time series are transformed from temporal to another domain to perform spectral analysis is a preferred method in HRV analysis: discrete cosine transform (Martis et al., 2014), discrete Fourier transform (Panina et al., 1996); fast Fourier transform (Chemla et al., 2005), wavelet transform (Isler & Kuntalp, 2007), Hilbert-Huang transform (Li et al., 2011).

The authors Chua et al. (2008) and Saliu et al. (2002) use second-order statistics (suitable for Gaussian distribution signals and linear systems) for HRV spectral analysis. But human heart activity cannot be described as a linear system and its action does not correspond to the distribution of Gauss. For this reason, the authors are looking for ways to address this discrepancy.

Non-traditional methods of analysis have been created over the years. Trigonometric regressive spectral (Rudiger et al., 1999) is a method that uses trigonometric regression functions to describe time intervals. The authors have been successfully applied this method in analyzing data from patients with diabetes and hypertension.

The authors (Krafty et al., 2014) describe the use of the penalized sum of squares for spectral analysis of HRV. The proposed method is applied to study the efficacy of the method of adults with insomnia and assumptions have been made about the efficacy of the healing process.

In a paper (Ling et al., 2017), the authors present the results of a study of pediatric patients with ventricular arrhythmias and with myocarditis by determining parameters in the time domain. The results obtained were compared with those of a healthy control group.

The classification of cardiac disorders caused by arrhythmias present authors (Jovic, Jovic, 2017). The researchers propose a new method (symbolic dynamics method and alphabet entropy) through which they perform automatic classification of cardiac arrhythmias; the surveys were conducted on a public database (PhysioNet MIT-BIH Arrhythmia Database).

3. Nonparametric methods for HRV analysis

HRV spectral analysis is a non-invasive, easy-to-apply mean for assessing cardiac activity, for monitoring fluctuations of autonomic function, and for monitoring the effect of the administered medication on a patient. HRV analysis of short-term records evaluates the dynamic activity of the heart over short intervals. HRV analysis of long-term records is suitable for making predictions about the development of a patient's disease.

When performing spectral analysis, the Power Spectral Density (PSD) is most often determined. This method provides information on how the power of the signal depends on the specific frequency.

The means of the spectrum analysis include parametric (based on the autoregressive model and the moving average model) and nonparametric (based on the Fourier Transform and based on the wavelets) methods. The advantage of the autoregressive model is that it does not interpolate the input data, which shortens the analysis time; however, its disadvantages are its complexity, the need to select an appropriate model for analyzing the input data, and this choice has a significant impact on the results obtained (Malik M. 1996), (Li et al., 2019). The authors of (Chemla et al., 2005) and (Silva et al., 2009) show that in some cases this method is not suitable for use (for example, in the study of patients with diabetes).

Discrete Fourier Transform, Fast Fourier Transform, and Welch Periodogram are nonparametric mathematical methods for HRV frequency analysis. The spectral analysis of the HRV is performed on the input data without being processed.

The Discrete Fourier Transform and Periodogram, which is created through this transformation, is a popular method for spectral analysis of HRV. This Fourier transform is very well studied and is suitable for the study of continuous, evenly distributed sequences. The time series of heart rate intervals are uneven, dynamic, and therefore Discrete Fourier Transform is not the most appropriate choice for spectral analysis of HRV. Algorithms using Fast Fourier Transform have the advantage of delivering results at low CPU time. The method does not produce correct results in a short series of data (for example 1-2 minutes) (Zeimen et al., 2013).

Both Discrete Fourier Transform and Fast Fourier Transform have prerequisites for introducing distortions and harmonics that do not actually exist in the signal spectrum (Krafty et al., 2014). For this reason, the input series is interpolated and a uniformly distributed sequence is created (Malik, 1996).

The Welch method turns out to be the most suitable of nonparametric methods by averaging the received periodograms from the time series RR overlapping intervals (Malik, 1996), (Welch, 1967).

The input data of cardiological intervals are divided into blocks (that in most cases overlap). The data points of each block are received varying degrees of weight by assigning them to a normalization factor. Usually, the normalization factor is calculated using a window function. This is followed by calculating the periodogram for each block, then averaging the resulting periodograms (Welch, 1967):

$$Periodogram(f) = \frac{1}{U.K.Num}\sum_{i=0}^{Num-1}\left|\sum_{j=0}^{K-1} x_i\,(j).w(j).e^{-2j\pi fn}\right|^2,$$

Where:

U – normalization factor;

K - elements in the blocks;

Num – number of blocks that overlapped;

$w(j)$ – window function;

$x_i(j)$ – input data;

f - frequency.

Results

Characteristics of patients. Investigations were performed on 44 Holter monitoring Records of 3 groups of Individuals (16 Healthy individuals, 17 patients with Ventricular tachycardia and 12 patients with PVC Arrhythmia).

The presented results are obtained based on spectral analysis on a 5 min block from long term (24 hours) records. The results were obtained using a software program created by the authors. The five minute blocks are part of the cardiology record through the day and the obtained results correspond to the daily activity of the studied subjects.

Statistical analysis. The obtained results are presented as mean ± standard deviation (mean ±SD). A T test was used for statistical processing of the results. The values of the parameters at which P_{value} is less than or equal 0.05 (5%) are considered statistically significant.

Table 1 presents the results of the analysis of heart rate variability in the frequency range of the two types of arrhythmias studied and a healthy control group. The studies conducted include the Power in Low Frequency (0.04-0.15 Hz) area and the Power in High Frequency (0.15-0.4 Hz, HF) area and the LF / HF ratio known as sympathetic balance.

Table 1: Frequency Domain HRV measures

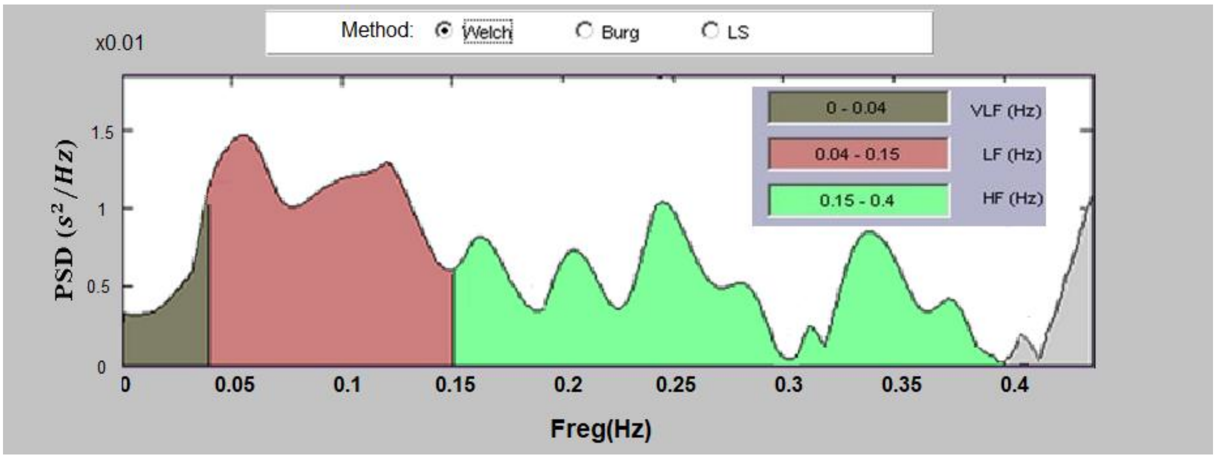
	LF $[ms^2]$	HF $[ms^2]$	LF/HF
A group with Ventricular tachycardia N=17	292.71±98.44	264.77±103.12	1.11±0.43
Group with PVC Arrhythmia N=12	247.16±83.09	303.05±11.94	0.82±0.74
Healthy Group N=16	1308.38±104.62	788.23±96.63	1.66±0.49
P_{value}	<0.0001	<0.001	<0.001

Source: the authors

The results in Table 1 show high average values of the spectrum in the low frequency range in healthy individuals (1308.38 ms^2), these values are significantly lower in the group of patients diagnosed with Ventricular tachycardia (292.71 ms^2) and they are even lower in the PVC Arrhythmia patient group (247.16 ms^2). In the high frequency range, the highest values are again in the group of healthy individuals (788.23 ms^2), lower values were obtained in the PVC Arrhythmia patient group (303.05 ms^2) and the lowest values in the Ventricular tachycardia patient group (264.77 ms^2). The sympathovagal balance ratio in the healthy group has values that are within the values for healthy individuals recommended by the variability standard (Malik, 1996). The sympathovagal balance ratio of the two arrhythmia groups has values that correspond to people with health problems (Malik, 1996).

Power spectral density (PSD) of HRV performed by the Welch Periodogram method is presented in Figures 1, 2 and 3. PSD is obtained at Very low, Low and High Frequencies in s^2/Hz. Figure 1 (healthy subject) shows high values for Power spectral density in all three frequency ranges studied. This is an indicator of high HRV values and indicates good overall health of the individual being tested.

Figure 1: PSD of a healthy subject

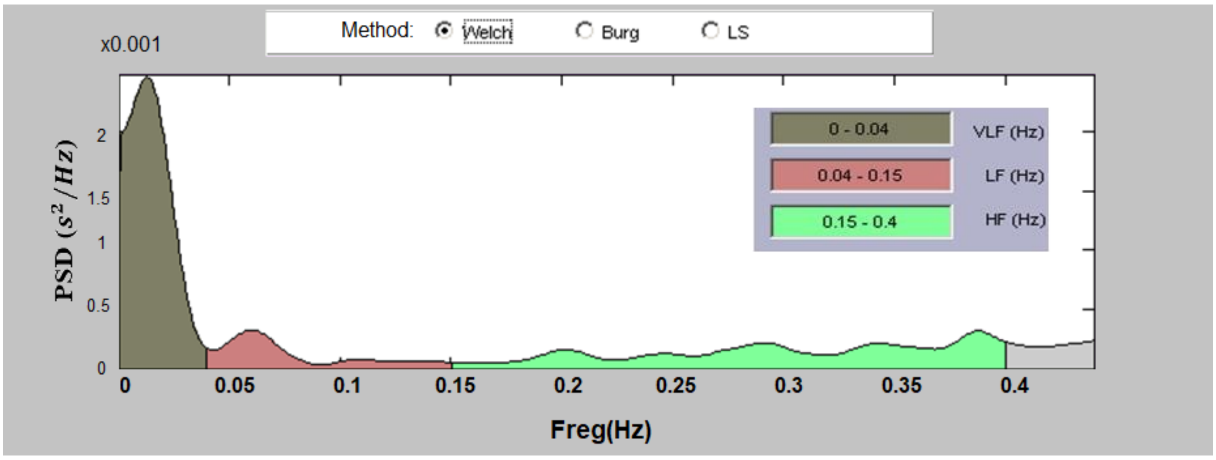


Source: the authors

Figure 2 (patient diagnosed with Ventricular tachycardia) shows low values for Power spectral density in the Low Frequency and High Frequency ranges. Values in the Very Low Frequency area are high. Low PSD values in the LF and HF area are indicative of low HRV values and are an indicator of the poor health status of the individual being tested.

Figure 3 (patient diagnosed with PVC Arrhythmia) shows low values for Power spectral density in the Low Frequency and High Frequency areas. Very Low Frequency values are higher than PSD values in LF and HF areas. The studied patients have low levels of HRV, which indicates a health problem.

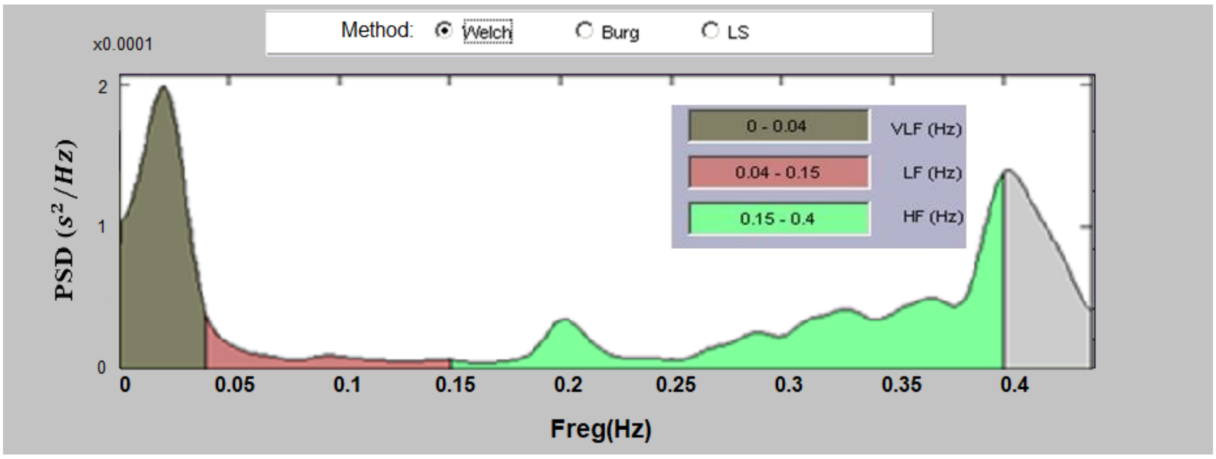
Figure 2: PSD of a patient with Ventricular tachycardia



Source: the authors

Figure 3 (patient diagnosed with PVC Arrhythmia) shows low values for Power spectral density in the Low Frequency and High Frequency ranges. Values in the Very Low Frequency range are higher than the PSD values in the LF and HF area. The patient under study has low HRV values, which indicates a health problem.

Figure 3: PSD of a patient diagnosed with PVC Arrhythmia



Source: the authors

4. Conclusion

HRV is known as an indicator of the health of the human body. HRV analysis is an effective means of determining the work of the heart. This study presents frequency analysis of the Holter data of patients diagnosed with Ventricular tachycardia and PVC Arrhythmia. The results of the analysis are compared with the results of the analysis of records of healthy individuals.

Based on obtained numerical and graphical results, the following conclusions can be made: In patients diagnosed with Ventricular tachycardia and PVC Arrhythmia has observed a significant reduction in Heart Rate Variability. In the heart disease arrhythmia, the power signal attenuation is observed in the high frequency range and the low frequency range.

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