BBT.HTI.501-2023-2024-1 Processing of Biosignals

Assignment 3: Heart Rate Variability (HRV)

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Introduction

Biological and physiological processes are complex, non-stationary and non-static in nature. The properties of these processes keep varying with time, for example, normal rhythm of the heart is repetitive, but the properties are not regular [1]. Heart rate variability (HRV) analysis is a method of quantifying the variability that occurs during the time interval between consecutive heart beats or R peaks in electrocardiogram (ECG) [1]. These time intervals can be visualized in a plot called tachogram.

HRV gives us information about neurocardiac dynamics and is considered the net output of parasympathetic and sympathetic systems of autonomic nervous system. Both systems work together and are essential in maintaining the internal functions of the body such as heart rate and breathing among others [1]. Frequency domain and time domain measures can be extracted from tachogram that gives us information about HRV. Some of the time domain measures extracted from HRV are standard deviation of NN interval (SDNN) which tells us about the spread of RR intervals, standard deviation of the averages of NN intervals in a 5-minute segment (SDANN), percentage of NN intervals that differ from each other for more than 50 milliseconds (pNN50), and root mean square of the differences between adjacent NN intervals (rMSSD) gives us information about beat to beat differences [1]. These measures inform us about both overall variation in the RR-intervals and beat to beat variations, easy to calculate and are indicative of HRV. However, to get specific information about sympathetic and parasympathetic activity, we might need to investigate frequency domain measures. Some other non-linear measures are investigating Poincare plot of RR intervals, 1/f spectrum, and detrended fluctuation analysis [1].

In healthy and young individuals, HRV is observed to be high, indicating body's ability to adapt to external stimuli. Low HRV indicates ageing, poor function of autonomic nervous system, body's inability to adapt during stress and external stimuli, diabetic neuropathy, and risk of death after cardiac arrest [1]. HRV is also used in athletes to analyze exercise performance. For example, low HRV in athletes may be due to overtraining [2]. HRV analysis is now becoming more popular mainly in diagnosing diabetic neuropathy and prediction of death after heart attack [1]. HRV is a good clinical parameter to investigate cardiovascular function and overall health of the patient.

Objective

In this report, we will extract time domain quantitative measures and non-linear measures from tachogram using ECG recording and study their interpretation for HRV.

Methods

An ECG recording of long period (approximately 22 hours) was recorded at 128 samples per second (Hz). The beat annotations of this recording were used to calculate and visualize HRV measures without doing preprocessing for missing or extra beats.

The RR-intervals were calculated and plotted (also called tachogram) against time to visualize the behavior of RR intervals. RR intervals were calculated by calculating the inter sample interval and multiply it by the difference between two subsequent R peaks. This variable was called *rr_intervals*.

The following time domain measures were calculated using their respective MATLAB functions:

1. SDNN:
   This measure was calculated for all RR intervals using function *std()* on variable *rr_intervals*.

2. SDANN:
   This measure was calculated by looping through the signal, taking 5-minute segments across the whole tachogram, taking average of RR interval in each segment, and calculating the standard deviation of the averages.

3. rMSSD:
   This measure was calculated by taking difference of *rr_intervals* using *diff()* command and then calculating root mean square of *rr_intervals* using *rms()* command.

4. pNN50:
   This measure was calculated by first identifying the RR intervals that are > 0.05 seconds, then adding it using *sum()* command and finally calculating the percentage of it by dividing over the length of the sum.

We also plotted the histogram of RR interval using *histogram()* command and non-linear Poincare plot of RR interval (nth) against the next RR interval (n+1) using *scatter()* command.

Results

A tachogram showing RR intervals in the whole ECG recording is illustrated in Figure 1:

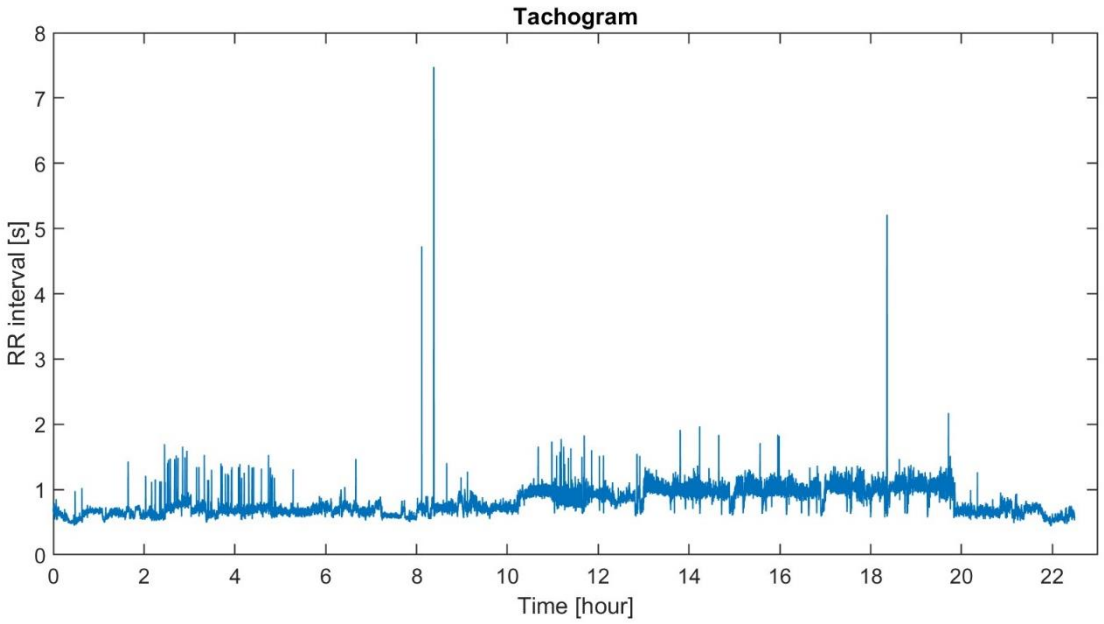

Figure 1: Plotting RR intervals against time.

The quantitative values of extracted HRV measures are provided in Table 1:

Table 1: Time domain measures and their values

Time-domain measures	Values
SDNN	0.1718 seconds
SDANN	0.1671 seconds
rMSSD	0.0580 seconds
pNN50	8.8186%

The histogram of the RR-intervals is plotted in Figure 2 to understand the distribution of the data:

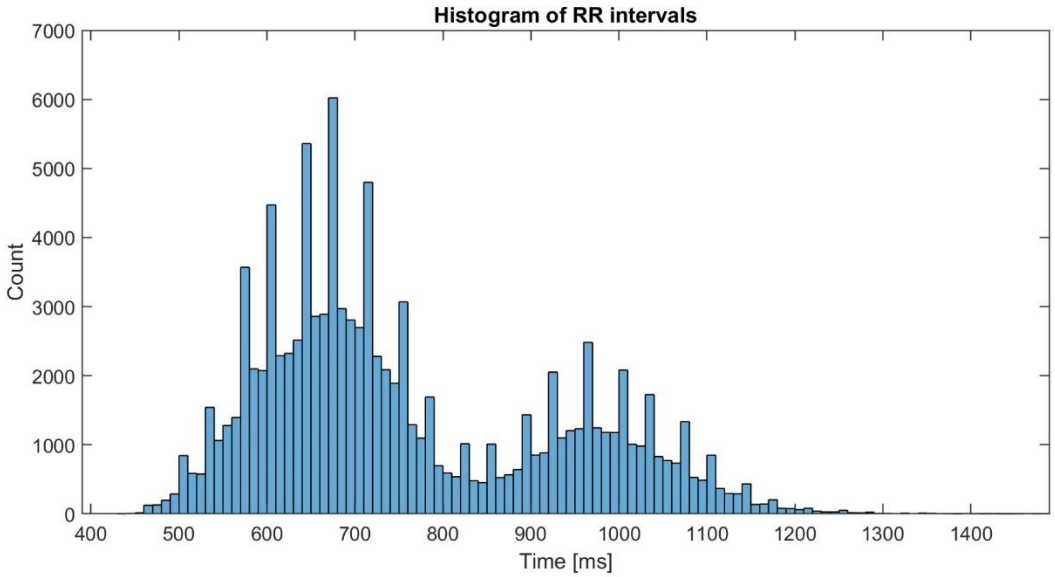

Figure 2: Histogram showing the count distribution of RR intervals.

One non-linear method of investigating RR intervals values, Poincaré plot is also shown in Figure 3:

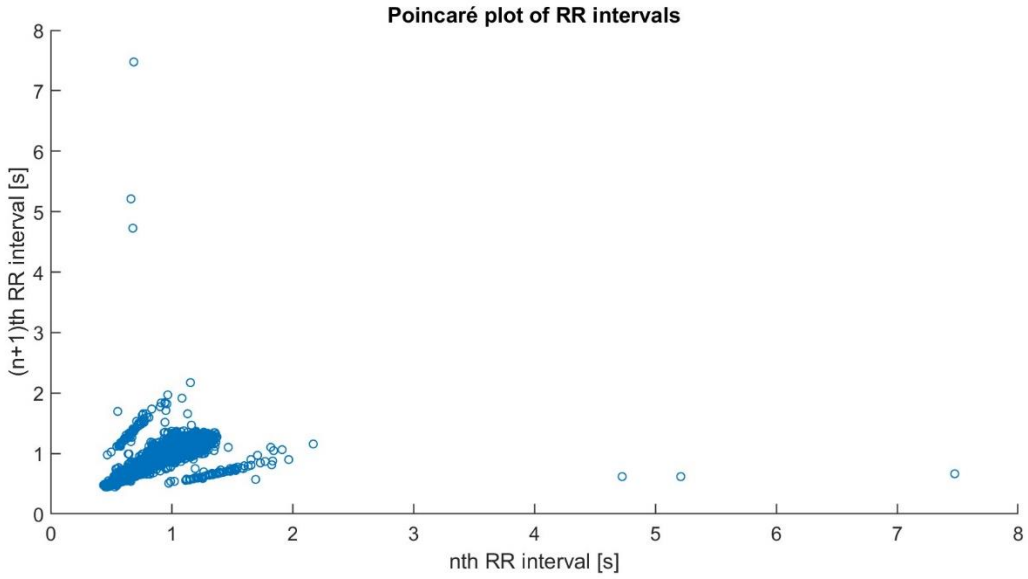

Figure 3: Poincaré plot of RR interval.

Discussion

While analyzing the tachogram in Figure 1, we can notice a few abnormally high amplitudes or peaks. These peaks tell us that the RR intervals or time between beats at those points are quite long. This indicates that there are missed beats for relatively long periods. We can also notice that there are many small peaks between 1 and 2 seconds while the remaining data is in a form of wave. The tachogram gives us some information about the unusually high intervals but it is quite hard to interpret the HRV from this alone. Therefore, other time domain measures were also calculated.

By looking at the values obtained of pNN50, it indicates that only about 8.8% intervals differ for more than 50ms from each other. For high HRV, more RR intervals should differ from each other for more than 50ms indicating that they are adapting to the stimulus and changes around them, and this value should be high. The values of SDNN and SDANN tell us that each beat varies with approximately 0.019 seconds from each other on average. This information only tells us the approximate variations in the whole data set and is useful in informing us about the effects of outliers. It can be deduced by the low values of these measures, that even though we have a few high intervals as outliers, our data set does not vary dramatically and is still quite robust.

rMSSD value tells us that on average, each beat varies about 0.058 seconds from each other. This can tell us about the HRV, however, to identify if this variation is high or low for this person and to deduce the health of their autonomic system, we need to know the age, gender, fitness level, and the context of measurement such as time of the day, physical activity level etc. These time domain measures are informative regarding the overall variation of the data but need to be put in context and further analysis with frequency domain measures may be required to obtain dynamics of autonomic system.

While looking at the histogram, we notice that most of the RR intervals lie between approximately 600ms to 700ms while the next highest count is between 900ms to 1100ms approximately. We also notice that after 1250ms, the count is quite low indicating that very small effect of outlier when comparing with mean RR interval. This means we can quite easily remove the outliers without affecting the valuable information of HRV.

The summarized and beat-to-beat insights into HRV can be seen in Poincare plot. Additionally, it reveals the HRV patterns correlated with three subclasses, distinguishing short and long interval variations. Moreover, Triangular methods, known for their robustness against outliers, are suitable for analyzing RR interval series for this purpose. It is important to note that the dataset exhibits two distributions in the histogram, therefore, two triangles would be required to accurately determine triangular indexes for each subclass.

Conclusion

HRV analysis can give valuable information about neurocardiac communication and function. We conducted HRV analysis by calculating different time domain and non-linear parameters. These parameters are highly sensitive to outliers such as missing heart beats. Therefore, it is important to identify these outliers beforehand, use techniques to correct the outliers and select methods that are not affected by artifacts.

References

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2. Aubert, A., Seps, B., & Beckers, F. “Heart Rate Variability in Athletes. Sports Medicine”, Sports Medicine, 2003. https://doi.org/10.2165/00007256-200333120-00003