THE IMPORTANCE OF SPECIFYING RR INTERVAL NORMALIZATION METHOD

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Abstract: The main objective of this article is to bring attention to RR intervals resampling. Many researchers dealing with HRV problematic neglect to mention which algorithm they are using in their research. Some of the commonly used methods are presented here and how an algorithm choice can affect final results of HRV spectral analysis is shown. Power spectrum for each method was computed and power of commonly used measures (HF & LF) is presented in table to highlight the possible differences.

Keywords: HRV, PSD, RR intervals, resampling, normalization, LF, HF

1 INTRODUCTION

Heart rate variability (HRV) has been gaining more attention not only as an indicator of heart condition, but also as a source of information about autonomic nervous system (ANS) [9] [2] [3] [11] [6]. Sympathetic and parasympathetic activity have main influence on instantaneous variation of heart rate. There are many methods to asses obtained data in time and frequency domain [3] [5] [4] [11]. Current research on HRV is focused on developing new methods and measures for discovering ANS pathologies [12] [14].

Widely used parameters for estimating ANS activity are high frequency (HF, 0.15-0.4 Hz) and low frequency (LF, 0.04-0.15 Hz) components of power spectrum density (PSD) [5]. The most common way to compute PSD is with fast Fourier transform (FFT). Raw RR intervals are series of unevenly sampled points in time, thus using FFT would not be appropriate for correct measurement of HF and LF coefficient. Resampling of RR intervals should follow. Some attention is drawn to RR preprocessing methods (artifact removal), with goal to increase discrimination capability of HRV parameters [8] [7] [10]. Shortcoming of many papers dealing with HRV issues are not considering this, or not providing any information about used approach despite there being several possibilities. The objective of this article is to present some of the methods used for RR resampling and show, that different choice of these methods and not providing any information on this topic lead to inconsistent results and zero reproducibility, thus bringing more confusion to this topic [1].

2 RESAMPLING METHODS

Methods for computing evenly sampled tachogram (series of RR intervals) are presented. Selected methods appears most commonly in research papers, but due to lack of information provided by researchers and similarities between them, it is difficult to definitely determine used method.

Interpolation is by far the most used method for computing new data points from discrete measured data. It provides estimation of unknown values between known data, depending on selected interpolation type.

2.1 NEAREST-NEIGHBOR INTERPOLATION

Nearest-neighbor interpolation is the simplest interpolation method. It provides additional data points of the same value as the nearest known value. As shown in Figure1a tachogram computed by this method contains sharp transitions between known values, which contaminates spectrum of this signal with ripples/comb especially in high frequencies (See fig.2b). This type of tachogram represents heart rate of the patient at that exact moment of time.

2.2 LINEAR INTERPOLATION

Nearest-neighbor in linear interpolation uses fitting of linear function to compute new data. Use of linear polynomials provide better transitions between data points Figure1b, thus reduces spectral contamination in high frequencies. Still it is the simplest approximation of unknown function.

2.3 CUBIC SPLINE INTERPOLATION

Cubic spline interpolation is special case of polynomial interpolation using low degree polynomials. This interpolation provides smooth polynomial functions, that fits together at known points. This method is probably the best choice for resampling RR data series and it seems to be the most used one.

2.4 MOVING AVERAGE

Use of moving average is not a method of resampling RR intervals, but sometimes it is considered as a better representation of slower changes in HRV when fast changes are not of interest. As this method cannot provide additional samples, it is usually computed from nearest-neighbor interpolation (beats per minute curve). This method provides very smooth tachogram, thus highly reducing high frequency components in the signal (See fig.2e). As a result using moving average for constructing tachogram is not a good method for spectral analysis (comparing HF & LF) and should be used only if researcher is searching for slowly changing variability [9].

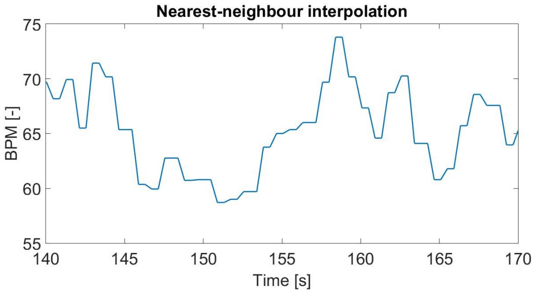
3 METHODS COMPARISON

For better understanding of differences between presented methods, spectra of tachograms are shown and also a table of HF and LF components power contribution to power of whole spectrum (0.003-0.4 Hz - area of interest). Because of concerns that some researchers may completely ignore resampling of RR interval, spectrum of unequally sampled RR series is also presented [10]. 1 Hz is used as a reference sampling rate for x axis, as it is the most probable representation in paper omitting resampling methods.

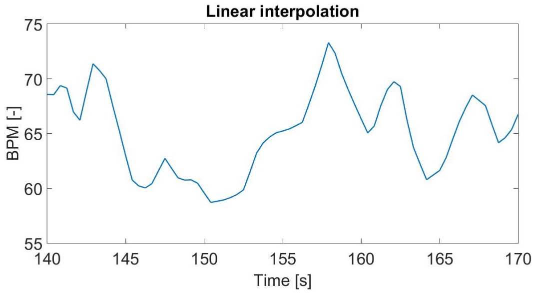
As you can see Figure2 it is obvious, that resulting power spectra differs greatly. Especially a drop in HF components can be seen (marked by doted line).This is also visible in table1. As expected power spectrum without any resampling method is the most chaotic and is the only one where we can not see peak at approximately 0.1 Hz, which is very distinguishable in other spectra (pointed out by arrow, caused by blood pressure oscillations [13]).

Table 1: Representation of LF and HF power spectral components

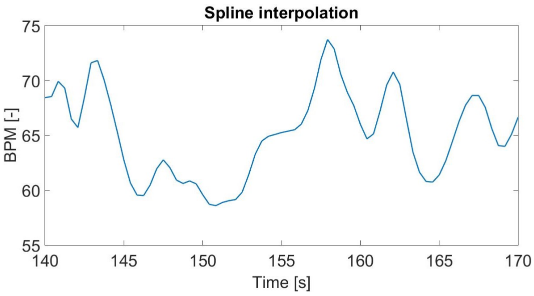
	No interp.	Nearest n.	Linear	Cubic	Mov. avg.
LF pow [%]	40,09	46,67	44,38	44,01	27,60
HF pow [%]	30,11	29,36	9,53	11,73	4,20



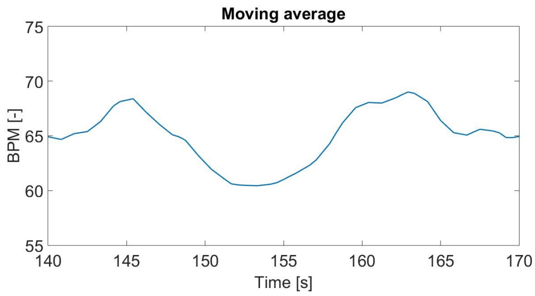
(a) Nearest-neighbor interpolation



(b) Linear interpolation

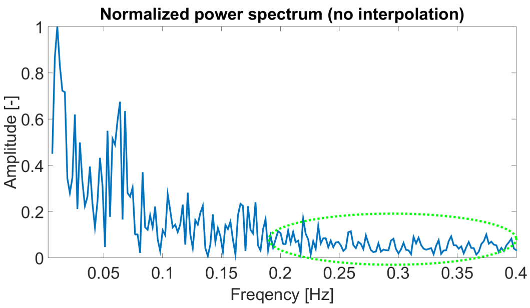


(c) Cubic spline interpolation

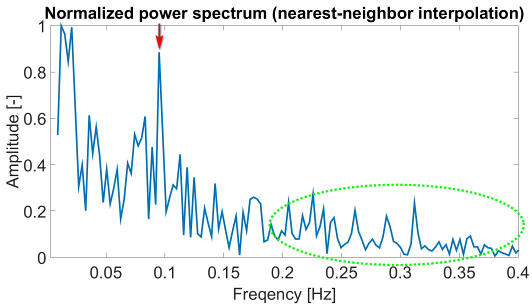


(d) Moving average

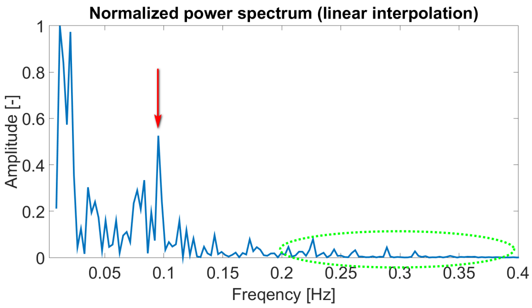
Figure 1: Sections of tachograms created by selected methods



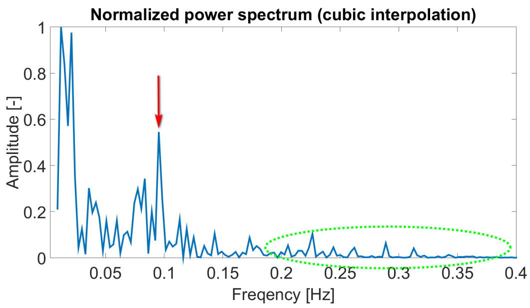
(a) Normalized power spectrum (no int.)



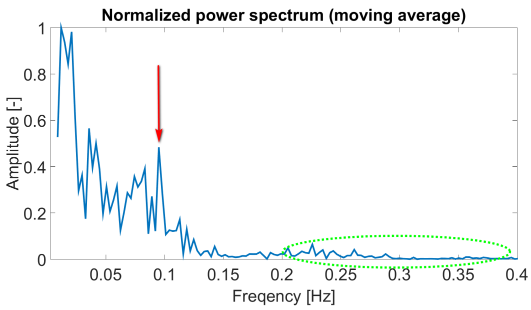
(b) Normalized power spectrum (Neighbor int.)



(c) Normalized power spectrum (linear int.)



(d) Normalized power spectrum (cubic int.)



(e) Normalized power spectrum (moving average)

Figure 2: Normalized power spectra

4 CONCLUSION

As this work shows different resampling methods have major influence on resulting spectra. Even though cubic spline interpolation is considered as an unspoken standard it is not used at all times. Also it does not always have to be the best method for other HRV measures.

Only some methods were compared and there are numerous other possibilities of altering RR intervals. Even the presented moving average method yields different results depending on chosen window size. Another possible method is convolution with window function applied to nearest-neighbor interpolation when there is influence of future RR interval expected on previous ones.

The goal of this work is not to show that one resampling method is superior to other, but to bring some attention to the issue. This would bring much needed clarity to various papers dealing with HRV analysis and could explain why similar experiments yield different results.

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