ANALYSIS OF HEART RATE VARIABILITY DURING RESPIRATION

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Abstract - This paper deals with a problem of signal processing of heart rate variability (HRV) with emphasis on a detection of similarity between the HRV and respiration signal. Different heart rate variability tests were used to reach this goal. We also have performed tests with spontaneous respiration signals in order to compare our results. Linear (mean, standard deviation etc.) and nonlinear methods (Poincaré plot), that work in both time and frequency domain, were used. A segmentation of the breathing signal took place within the time domain method. It gives a basic notion of normal and controlled breathing pattern and the information about a time delay of the HRV. Influence of naturalness of breathing pattern was also detected. The known fact that the HRV stay similar to previous pattern during first 20seconds of apnea phase (special respiration pattern with no breathing) was confirmed. A result of this research is a confirmation of the previous results and a basic detection of the time delay between the HRV and respiration.

I. INTRODUCTION

Heart rate isn't constant, this paper deals with a curve that represent the variability of heart rate during respiration and during the apnea period. However heart rate variability depends on activity of autonomic nervous system and respiration. Other factors such as stress, physical activity etc. influence HRV either, but it can be considered as a part of ANS influence. During normal uncontrolled breathing respiration seems to influence HRV for less than 10%, but controlled respiration increases this influence up to almost 50%, so the ANS mechanisms has less influence [1].

Frequency and time domain parameters of HRV indicate the health state of patients. For clinical use some breathing test are usually applied such as orthostatic, valsalva's, apnea or deep breathing test (test of deep breathing and apnea test were used in this study).

The HRV curve that is detected during these tests are signal processed in time and frequency domains . Usually the heart rate variability is studied in frequency domain [2, 3], because it seems to be more factors that can be detected from total power of different frequency bands. This paper is specialized basically on time domain analysis and on analysis of respiratory curve itself.

II. MATERIAL

To describe dependences between heart rate and respiration pattern we used a signal database that was provided in our laboratory. The database consists of 4 different signals of 15 young (21-25, 35) and healthy people for at an average 5 different breathing patterns.

These signals were (see fig 1.):

1. electrocardiogram - ECG (II recording)
2. photoplethysmogram - PPG
3. breathing signal provided by an elastic band, spanned around the chest
4. breathing signal provided by a thermistor near the nose

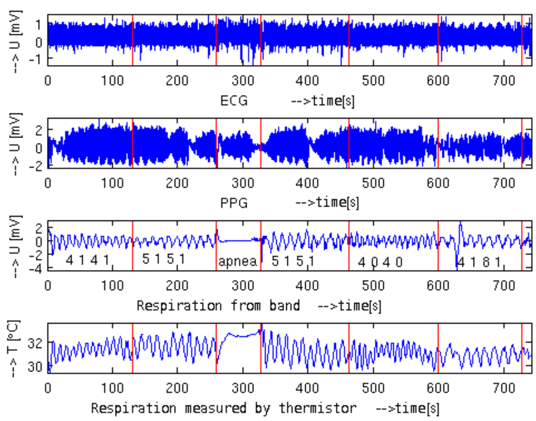


Fig. 1. Signals that were measured during controlled respiration. Patterns were changing continually after 2minuts. The apnea phase duration was about 62s.

Breathing patterns that were used to record all biological signals were:

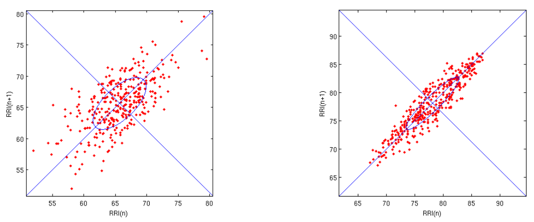
1. Normal respiration (no breathing pattern) - 5 min duration
2. Natural breathing pattern to prepare for the breathing test - 4-1-4-1* - 2min duration
3. The test of deep breathing before apnea - 5-1-5-1 - 2min duration
4. Apnea phase - 62s duration
5. The test of deep breathing after apnea - 5-1-5-1 - 2min duration
6. Not natural breathing pattern - 4-0-4-0 - 2min duration
7. Exotic not natural breathing pattern - 4-1-8-1 - 2min duration

III. METHODS

To detect the dependences between respiration and heart rate variability curves were used linear and nonlinear mathematical methods for both time and frequency domains.

Simple linear methods in time domain are calculation of quantiles, median and different kinds of standard deviation. One of the most important value, that was obtained using this methods was NN50 parameter, that determines the quantity of short R to R peak intervals which duration is less then 50ms (standard length of RR interval for healthy people is about 380ms).

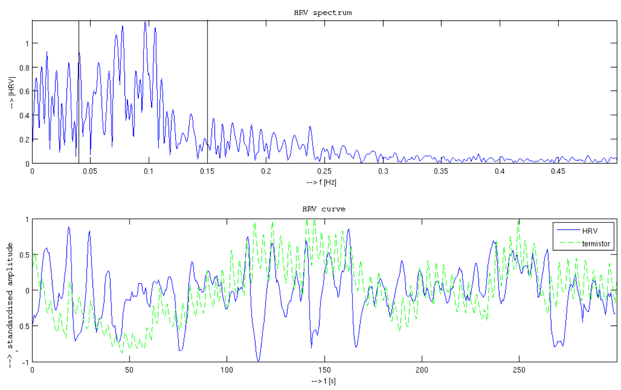
Poincaré plot was also used in this paper (see fig.2) as a nonlinear time domain method, that was a good tool to visualize the information of heart rate variability curve of both long- and short-term record. The dependence between RR interval and previous one (RR_{i-1}) is used to compose this plot. And it's usually used to detect quality of HRV curve - healthy subject has at eye symmetric plot.



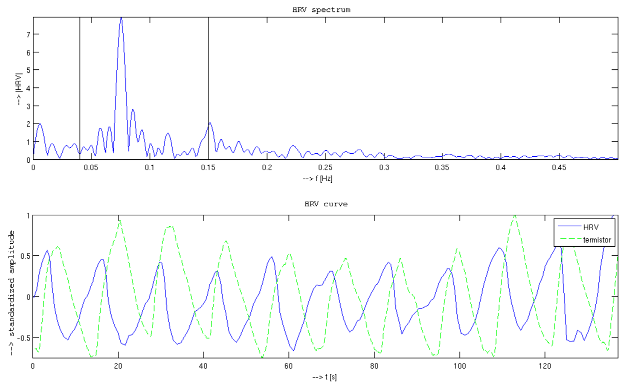
(a) (b)

Fig. 2. Illustration of Poincaré plot for 5 minutes long signal (a) for uncontrolled respiration and (b) controlled respiration for deep breathing test

The second part of HRV analysis, that was provided, was analysis in frequency domain. Because HRV of healthy subjects obtains to be almost periodical, frequency domain methods are usually more used for exact description of it's curve. The main parameters that were investigated in this paper were the total power in 3 bands: very low (less than 40mHz), low (between 40 and 150mHz) and high (between 150 and 400mHz) frequency band. Differences between these parameters in different breathing patterns were monitored.



(a)



(b)

Fig. 3. Power spectrum for (a) uncontrolled respiration and (b) respiration during deep breathing test.

III. RESULTS

Healthy, young and untrained subjects has almost periodical HRV curve behavior during normal respiration, although the curve doesn't correlate with respiration properly one can detect a breathing pattern even without previous analysis.

Progress of parameter in time domain indicates the influence of naturalness of breathing pattern on heart rate variability. Although the mean of the length of RR interval doesn't seem to change significantly, the quantity of short HRV segments during deep breathing test decreased comparing to natural breathing and not natural breathing patterns (with no pause between expiration and impiration).

Spots on Poincaré plot of controlled respiration cumulates along axis and the center, while PP's spots that were measured during patternless respiration are more spread over the surface of the plot. Mentioned fact is caused of rather chaotic behavior of HRV curve when uncontrolled respiration occurs.

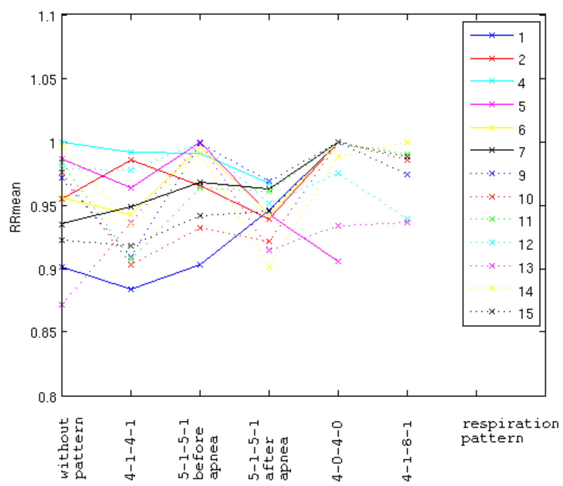


Fig. 4. RRmean parameter progress for different breathing patterns. The breathing pattern is described by value of impiration time, duration of breath hold in impirium, expiration time and time of breath holding in expirium - all values are in seconds.

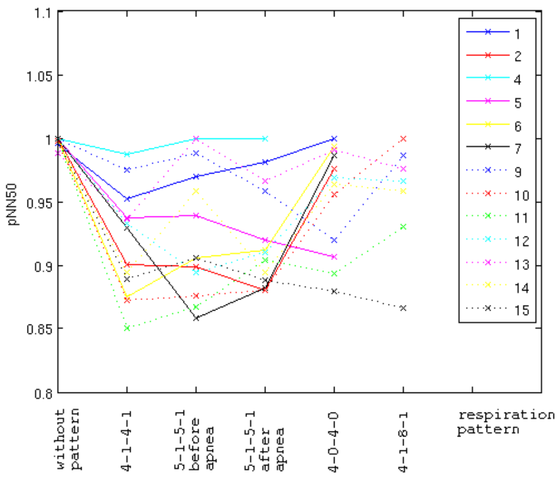


Fig. 5. NN50 parameter progress for different breathing patterns.

Analysis in frequency domain is a good demonstration of accentuation (sharpening) of the respiration frequency - during normal breathing it is almost impossible to detect the respiration frequency in spectrum of HRV, but during controlled respiration even higher harmonics.

Because it is possible segment the respiration signal, measured by thermistor into expiration and breathing in parts, the similarity of HRV and respiration periods were detected. The fact of similarity is valid for all controlled respiration patterns, one period of HRV curve matches with one period of respiration, bud delay between respiration and HRV period is difference regarding of breathing pattern.

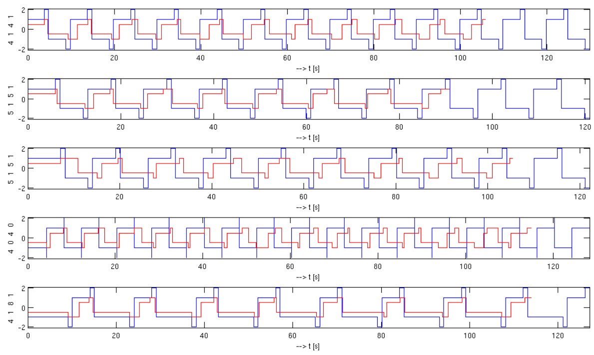


Fig. 6. Breathing patter detection from respiration signal measured by thermistor

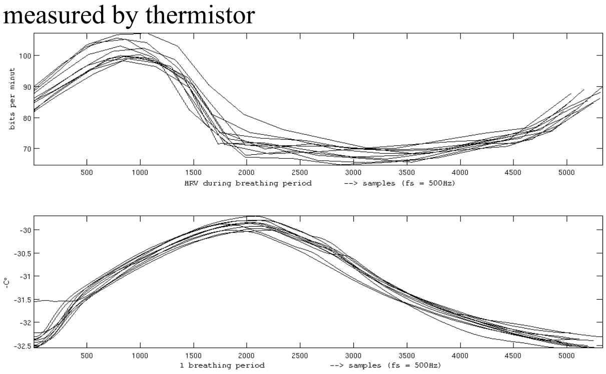
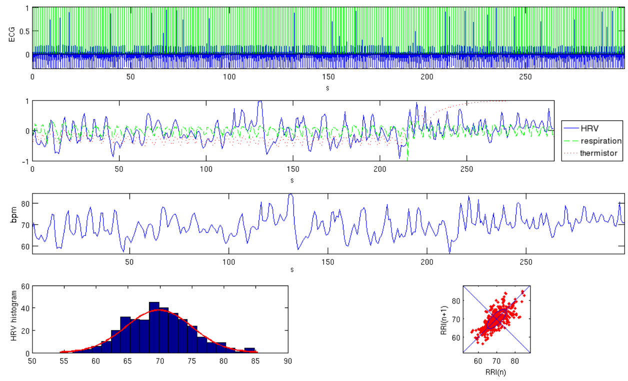
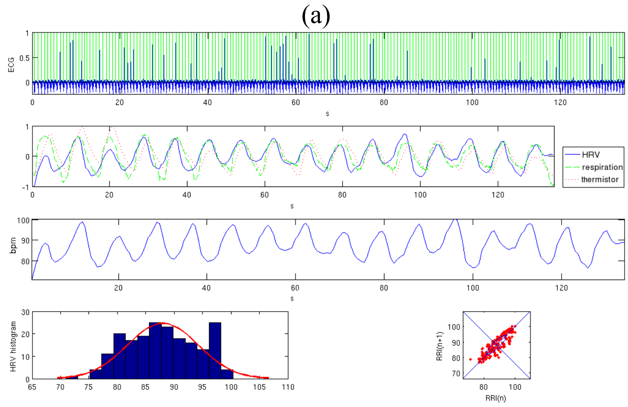


Fig.7. Respiration period compare to HRV period during controlled breathing by 4-1-4-1 pattern.



(a)



(b)

Fig. 8. HRV curve for (a) natural and (b) controlled respiration.

IV. CONCLUSION

This paper considers with dependences between heart rate and respiration. Methods in time and frequency domains that were used to detect parameters of heart rate variability show high dependence of HRV on controlled respiration. Untrained subjects don't seem to have a strong dependence of heart rate variability on respiration curve during uncontrolled breathing, while a trained person's dependence can be seen properly.

V. ACKNOWLEDGEMENT

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VI. LITERATURE

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