TIME AND FREQUENCY DOMAIN ANALYSIS OF FIVE HEARTBEAT TYPES

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The analysis of the electrocardiographic (ECG) signals, especially the QRS complex as the most characteristic wave, is a widely accepted approach to study and to classify cardiac dysfunctions. Five heartbeat types were studied (normal beats, ventricular extrasystoles, left and right bundle branch blocks and paced beats), searching for specific behavior in the timing and the frequency content of the QRS complex, due to changes in the rhythm origination and the conduction path. In the time domain the interbeat differences of the RR intervals were evaluated. In the frequency domain the QRS power spectrum was estimated by fast Fourier transform and a summary power spectrum in narrow frequency bands of 0.5 Hz (FFT-BPS) was calculated. Specific patterns of the FFT-BPS for each heartbeat type were derived and differences in the spectral frequencies were assessed. The observations allowed to define a spectral based parameter set, which jointly with the RR intervals could be easily processed by a standard classifier for the heartbeat type.

Keywords: heartbeat classification, QRS complex, Fourier transform, RR intervals

1. INTRODUCTION

Analysis of the electrocardiogram (ECG) for detecting different types of heartbeats is of major importance in the diagnosis of cardiac dysfunctions, due to abnormal changes of both the rhythm origination and the conduction path. Automatic classification of the heartbeats has been previously done using RR intervals [1], as well as using a variety of features to represent the alterations of the QRS waveform, most popular of which are based on the QRS morphology [1, 2]. More sophisticated methods apply QRS template matching procedures, such as the Matching Pursuits [2] to expand the QRS waveform into a single time-frequency basis, like the wavelet basis. Other authors prefer to avoid the fixed basis decomposition of the heartbeats and to study only the ECG frequency content by Fourier transform. Minami et al [3] classified the spectrum for three kinds of rhythms: supraventricular rhythm, ventricular rhythm and ventricular fibrillation. However, the defined arrhythmia classes are too general and clinical treatments in each class are not identical. More detailed heartbeat classification is necessary for the automatic diagnostic systems and therefore we need spectral analysis data of definitive heartbeat types.

It is the aim of the present work to study the frequency spectrum of five heartbeat types. We expect specific spectral distributions which facilitate the derivation of spectral pattern for each heartbeat type. Adequate estimation of this pattern is important to define a spectral based parameter set, which reliably identifies each one of the heartbeat types. We suggest improving the confidence of the feature set by additional analysis of the heart-rate variations based on assessment of the difference between the coupling RR intervals for each beat. The investigation is directed to computer-based ECG systems and to enhancement of their diagnostic ability.

2. METHOD

2.1 Heartbeats

ECG signals from the internationally recognized database MIT-BIH were used [4]. For each heartbeat the fiducial point and the original annotation were accepted. The study involved the five largest heartbeat types which feature with particular behavior of the QRS waveform: (i) N - sinus beats with normal conduction path through the ventricles (Fig.1a); (ii) V – ventricular extrasystoles generated by ectopic centres in the ventricles (Fig.1b); (iii) R - sinus beats with blocked conduction through the right bundle branch (Fig.1c); (iv) L - sinus beats with blocked conduction through the left bundle branch (Fig.1d); (v) P - beats stimulated by a pacemaker (Fig.1e). Each heartbeat type was represented by 200 beats selected from all ECG recordings. The QRS complex was extracted within a fixed-length window around the fiducial point, starting about 50 ms before it and ending about 130 ms after it. The QRS window contained 64 samples (18 before, 46 after) for sampling rate of 360 Hz.

2.2 Interbeat RR interval difference

This parameter is calculated according to Equation (1) and represents the difference between the durations of the two RR intervals, surrounding the tested heartbeat (with index n) – see Fig.1a, the ECG trace. The normalization towards the mean value of the previous five consecutive RR intervals is applied, in order to achieve a value independent from the heart rate.

$$(1) \qquad RRDiff_n = \frac{RR_n - RR_{n-1}}{(\sum_{i=n-7}^{n-2} RR_i)/5}.100\,(\%)$$

2.3 Frequency domain analysis

Each QRS complex within the window of 180 ms is processed by fast Fourier transform (FFT) and than the power spectrum is calculated. Before computing FFT, a Hanning window is applied to suppress the discontinuities due to possible adjacent P and T waves.

3. RESULTS

Signal processing, statistics and frequency domain analysis were implemented in the software package MATLAB 7.0. The parameter *RRDiff* was calculated for each studied beat and statistical analysis was applied to derive categorized histograms for the five beat classes – N, V, R, L, P (see Fig. 1, the left plots).

Besides, for each QRS we estimated the FFT power spectrum and the summary power spectrum in narrow frequency bands of 0.5 Hz (named FFT band power spectrum, FFT-BPS). The latter was calculated for all individual beats and the results are presented all together over the maps in Fig. 2, shown on separate subplots for the five beat classes – N, V, R, L, P. The X-axis corresponds to the frequency, the Y-axis shows the beat number, and the colored map represents values between 0 and 1 of the FFT-BPS, calculated in normalized units.

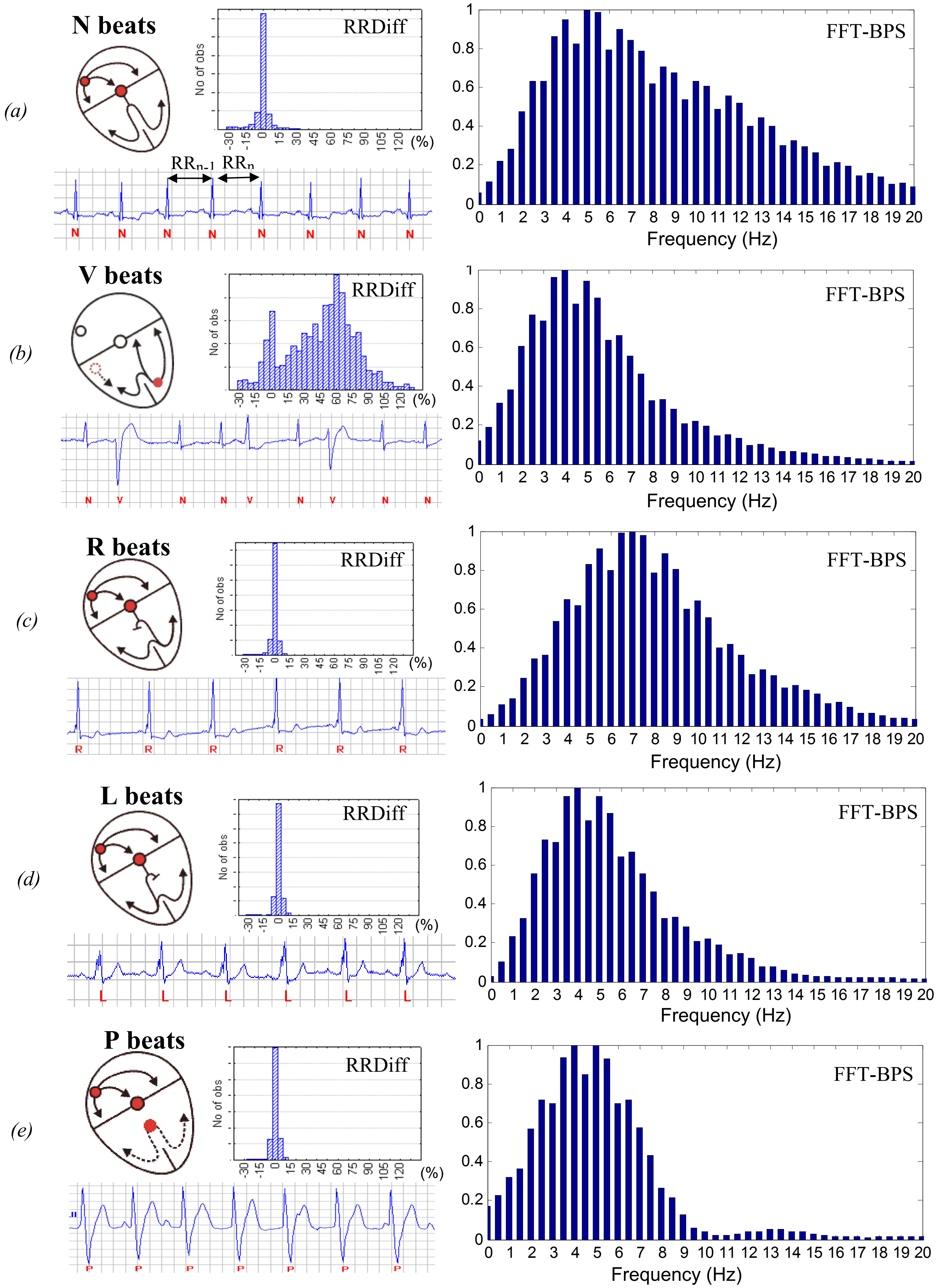

Figure 1(a-e). Five beat types (N,V,R,L,P) are represented by the following graphs:
(i) Heart Model: rhythm origination and conduction path;(ii) ECG Trace with QRS annotation marks;
(iii) RRDiff Histogram; (iv) FFT-BPS - the summary spectrum in 0.5 Hz frequency bands, the pattern spectrum.

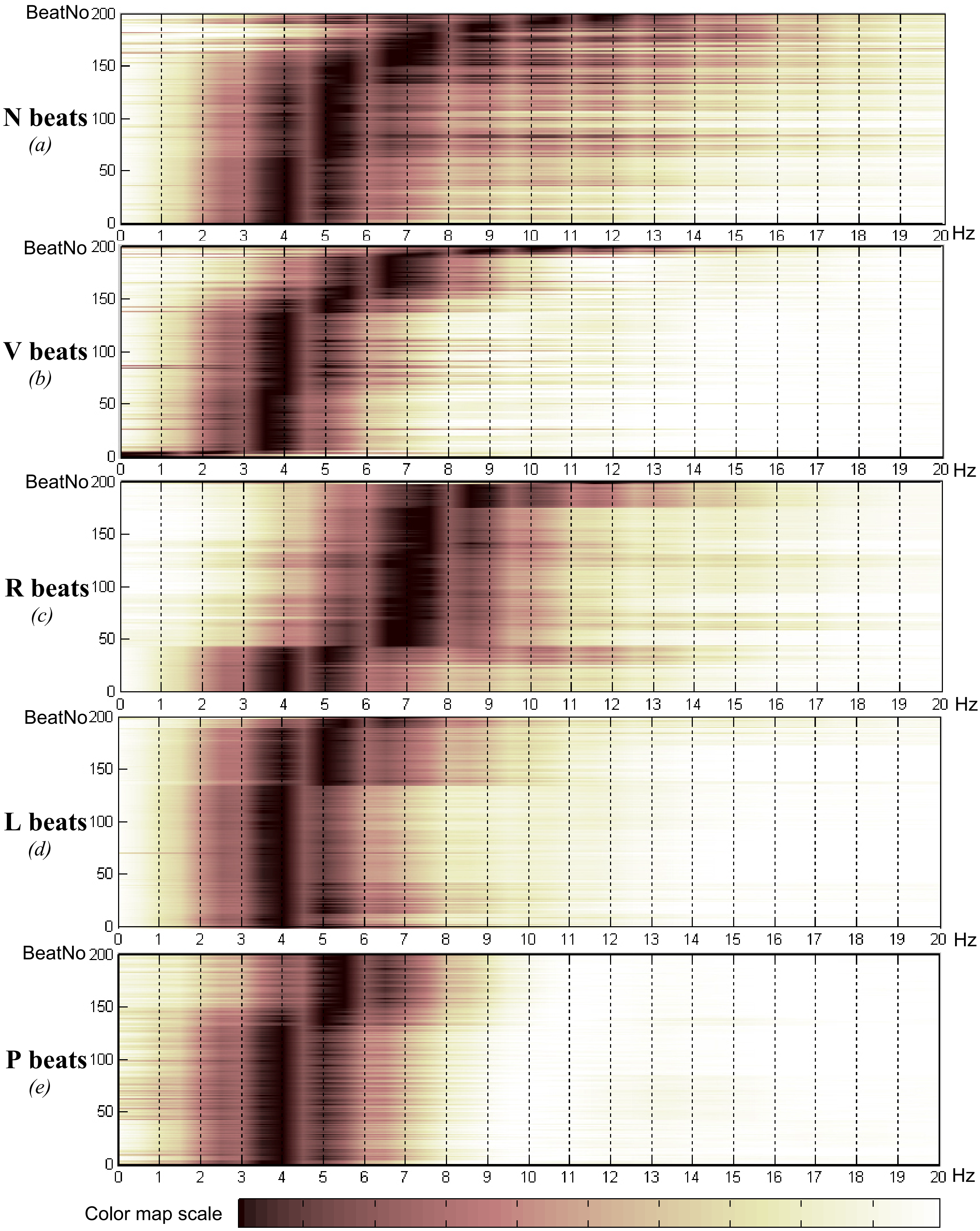

Figure 2(a-e). FFT-BPS maps for all beats categorized in 5 groups (N,V,R,L,P). The X-axis corresponds to the frequency, the Y-axis shows the beat number, and the colored map represents FFT-BPS in normalized units (values between 0 and 1).

Considering all QRS complexes we derived a specific pattern of the FFT-BPS for each beat class (see Fig. 1, the right plots). The quantitative assessment of the FFT-BPS patterns was applied at different amplitude levels, e.g. 0.25, 0.5, 0.75 and 0.95 for both the rising and the falling edge of the pattern envelope. The measured spectral frequencies are summarized in Table 1. Fig. 3 depicts the data in Table 1 and it is included for better visual interpretation of the frequency differences in the FFT-BPS patterns for the 5 beat classes.

Beat Type	Spectrum Rising Edge				Spectrum Falling Edge			
	Level 0.25	Level 0.5	Level 0.75	Level 0.95	Level 0.95	Level 0.75	Level 0.5	Level 0.25
N	1.5 Hz	2.5 Hz	3.5 Hz	5.0 Hz	5.5 Hz	7.5 Hz	12.0 Hz	15.5 Hz
V	1.0 Hz	2.0 Hz	2.5 Hz	3.5 Hz	4.0 Hz	5.5 Hz	7.0 Hz	9.0 Hz
R	2.0 Hz	3.5 Hz	5.0 Hz	6.0 Hz	7.5 Hz	9.0 Hz	10.5 Hz	13.5 Hz
L	1.5 Hz	2.0 Hz	3.5 Hz	3.5 Hz	4.0 Hz	5.5 Hz	7.0 Hz	9.0 Hz
P	1.0 Hz	2.0 Hz	3.5 Hz	4.0 Hz	5.0 Hz	5.5 Hz	7.0 Hz	8.0 Hz

Table 1. Frequencies for which the rising and the falling edges of the FFT-BPS pattern (of N, V, R, L, P beats) cross levels of 0.25, 0.5, 0.75 and 0.95.

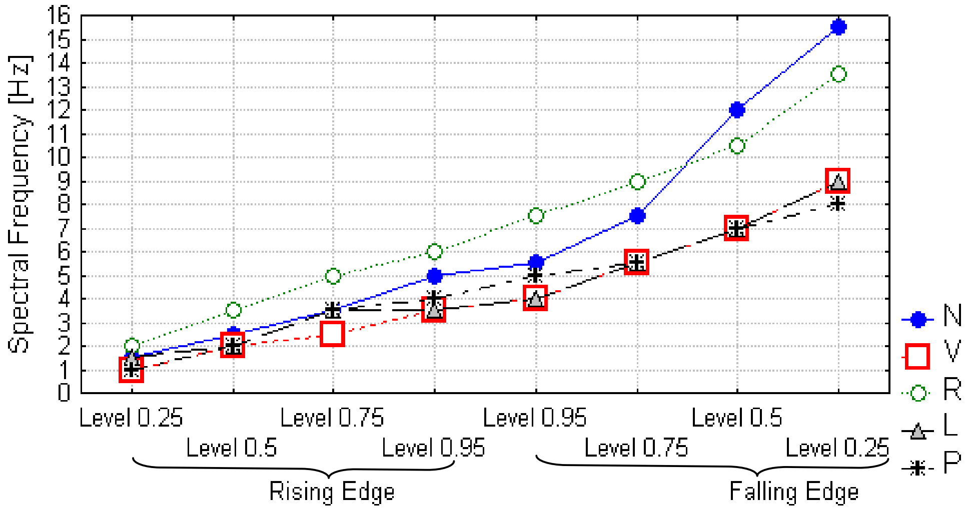

Fig. 3. Relation between the FFT-BPS pattern frequencies and the quantified levels (0.25, 0.5, 0.75 and 0.95) of the rising and the falling FFT-BPS edges.

4. Discussion and Conclusions

Most of the cardiac monitors employ RR interval analysis for identification of proarrhythmic events associated with heart-rate variation. We studied the specific deviations of the RR intervals surrounding the heartbeat in order to give indications about the type of the heartbeat. Considering the *RRDiff* statistical distributions for the studied 5 heartbeat types (Fig. 1), we observe the unique peak around zero for all QRS complexes with supraventricular origin (N, R, L), as well as for the P beats with fixed timing (*RRDiff*<15% in 95.4% of all N beats, and in more than 99.5 % of all R, L, P beats). This means that the mentioned above heartbeats are naturally coming at almost even time periods, so they are inseparable by a monitoring system analyzing RR intervals only. The simple RR interval analysis is applicable just for recognition of ventricular ectopic beats (Fig. 1b) which appear before the normal RR interval and are followed by complete (rarely by incomplete) compensatory pause. Our observations show *RRDiff>15%* in more than 83 % of all V beats. Unfortunately, many ectopic beats occur with equal coupling RR intervals, e.g. the interpolated beats, because of the great variety of cardiac dysfunctions.

The next step of our investigations involved frequency domain analysis of the QRS complexes. We searched for specific spectral differences among the studied 5 heartbeat types. Although the individual FFT-BPS observations show specific distributions within the 5 beat classes (Fig. 2), it is difficult to make direct conclusions about these differences. A quantitative assessment is based on FFT-BPS patterns derived for each beat type (Fig.1). The following conclusions could be formulated considering the results in Table 1 and Fig. 3:

- **N beats**: Their spectra contain specific frequencies which can discriminate them among all other beat types. The levels which can be used to identify at most the N beats are: for the rising edge - 0.95, for the falling edge - 0.95, 0.75, 0.5 and 0.25. We can note the tendency to preserve high frequencies in the spectrum.
- **V beats**: Their spectra distinguish from the spectra of both N and R beats at all levels because of shifting towards low frequencies. Despite the lowest frequencies observed for V beats, the problem is to discriminate the spectra of V, L and P beats. V beats differ from L beats only at spectral levels 0.25 and 0.75 for the rising edge. V beats differ from P beats at spectral levels 0.75 and 0.95 for the rising edge, and at spectral levels 0.95 and 0.25 for the falling edge. Based on these results we recommend managing the recognition of V beats first by RR intervals analysis and in supplement by a frequency domain analysis.
- **R beats**: Their spectra distinguish from all other beats at all spectral levels because of shifting towards high frequencies.
- **L beats**: They can be easily recognized from N and R beats but they are hardly separable from V and P beats, all with low frequency content. L beats differ from V beats only at spectral levels 0.25 and 0.75 for the rising edge. L beats differ from P beats at spectral levels 0.25 and 0.95 for the rising edge, and at spectral levels 0.95 and 0.25 for the falling edge. The discrimination between L and P beats is relatively complicated problem, regarding their similar spectra, as well as their periodical interbeat RR intervals.
- **P beats**: Their spectra are similar to these of V and L beats and all points discussed above should be considered.

The observed differences between the FFT-BPS patterns, derived for each of the 5 beat types (N, V, R, L, P), propose a spectral based parameter set, which jointly with the RR intervals could be easily processed by a standard classifier, such as the K-th nearest neighbour rule, fuzzy logic, neural networks, discriminant analysis, ect.

5. References

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