

# Comparison of Atrial Rhythm Extraction Techniques for the Estimation of the Main Atrial Frequency from the 12-lead Electrocardiogram in Atrial Fibrillation

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## Abstract

*One of the greatest challenges in analysis of the atrial rhythm from the ECG is to distinguish the atrial component from the large ventricular components. Our aim was to compare three techniques of atrial rhythm extraction from three groups working on this problem. 12-lead ECG data from 7 patients in atrial fibrillation were analysed. For extraction of the atrial rhythm, spatiotemporal QRST cancellation was performed by the Lund group, blind source separation by the Valencia group, and principal component analysis by the Newcastle group. Peak atrial frequency was determined by Fourier transform of the signal with the largest atrial activity. All algorithms were successful in distinguishing the atrial rhythm from the low frequency ventricular rhythm. The mean (range) atrial frequency was 6.5 (5.9 - 7.6) Hz (Lund), 6.7 (5.7 - 7.9) Hz (Valencia) and 6.5 (5.9 - 8.2) Hz (Newcastle). There were no significant differences between the atrial frequencies estimated by each of the techniques.*

## 1. Introduction

Atrial fibrillation is a common arrhythmia in old age with increased risk of stroke and death [1]. The arrhythmia is diverse in its presentation and there are a number of different treatments which aim to restore sinus rhythm [2]. Analysis of the atrial rhythm, before, during and after treatment, provides a means by which to quantify the effects of treatment and to assess the effectiveness of treatment on the different characteristic types of atrial fibrillation. One of the greatest challenges in analysis of the atrial rhythm from the ECG is to distinguish the atrial component from the large ventricular components, namely the QRS and T waves. In this collaborative project, our aim was to compare, by analysis of the main atrial frequency, three techniques of atrial rhythm extraction from three groups working on this problem. The Lund group have developed spatiotemporal QRST cancellation, an extension of a technique for subtraction of the QRST waveform from each ECG lead which has been used for a number of years. Blind source

separation and principal component analysis have only recently been applied to the problem of atrial rhythm extraction by the Valencia and Newcastle groups respectively, but are well established signal processing techniques in the fields of image analysis and data communications.

## 2. Methods

### 2.1. Data

12-lead ECGs of 7 patients with atrial fibrillation were recorded to computer at the Freeman Hospital, Newcastle. The sampling rate was 500 Hz and the amplitude resolution was less than 5  $\mu$ V. Recording duration analysed was 60 s. The ECGs were copied and distributed to the groups in Lund and Valencia.

Ventricular rate was derived for each patient from the mean heart rate over the 60 s recording.

### 2.2. Atrial rhythm extraction techniques

#### 2.2.1. Spatiotemporal QRST cancellation

The Lund group applied the spatiotemporal QRST cancellation technique [3]. The ECGs were resampled at 1 kHz and filtered using a 0.3 Hz high pass filter to reduce baseline wander prior to QRST cancellation. Beat detection and cross-correlation based beat classification were performed such that all normal beats belonged to one class and different types of ectopic beats belonged to different classes.

Morphologic beat-to-beat variability caused by variations in the electrical axis of the heart, such as during respiration, would exist within all beat classes, potentially causing mismatch and QRS residuals when applying beat subtraction based on classical ensemble averaging. In order to compensate for such morphologic changes the spatiotemporal method (applied to all beat classes by means of linear transformations) optimally combined beat averages from the different leads to cancel the ventricular activity in

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each lead. An atrial signal was derived for each ECG lead.

### 2.2.2. Blind source separation and principal component analysis

The Valencia group applied the blind source separation technique [4,5] and the Newcastle group applied principal component analysis [6]. For blind source separation the ECGs were band limited to 0.5 Hz to 60 Hz prior to analysis. No preprocessing was used with the principal component analysis.

Blind source separation and principal component analysis are closely related techniques for the transformation of

multivariate data [7]. The aim was to recover a set of source signals from the observation of linear combinations of the sources. In this application the sources were the atrial and ventricular activities which were assumed to be physically decoupled, so that both could be considered as generated by statistically independent bioelectric sources. The observations of these sources were the 12-lead ECG signals. The 12-lead data were then represented by a new set of independent variables with the atrial component apparent in one or two variables. In the application of these techniques principal component analysis used second order (Gaussian) statistics, and in the case of blind source separation higher order statistics and information theory were used.

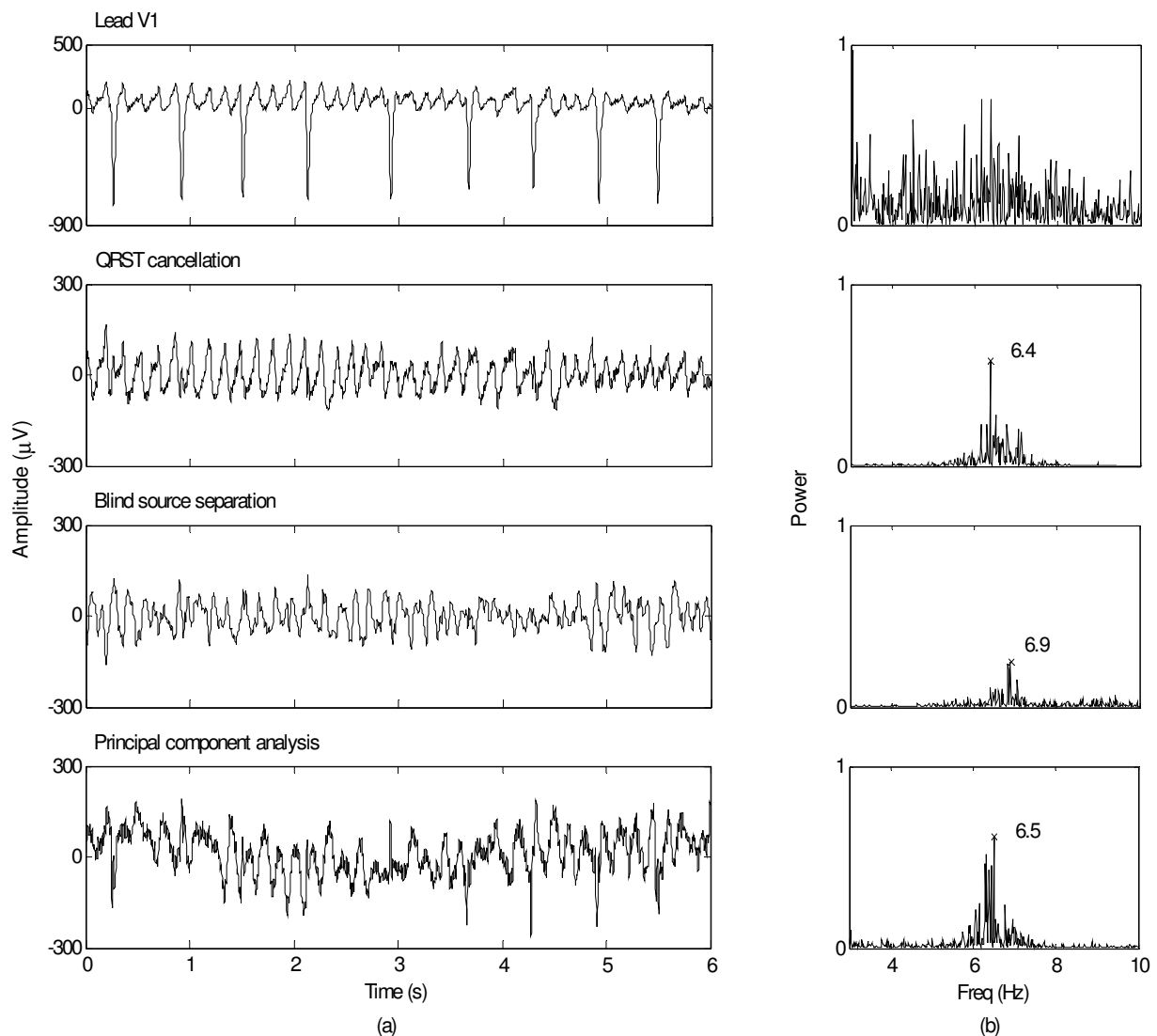


Figure 1. a) Lead V1 of a patient in atrial fibrillation with extracted atrial signals derived by each extraction technique. b) Frequency spectra of each of the time domain signals shown in a).

### 2.3. Frequency analysis

Each of the atrial rhythm extraction techniques were implemented in MATLAB (The Math Works Inc, Natick, USA) and the resulting atrial signals were sent as MATLAB data files to the Newcastle group for frequency analysis. Frequency analysis was carried out using the periodogram method by applying the fast Fourier transform to the 60 s section of atrial signal. The signal with the largest amplitude atrial component was selected for analysis by visual inspection of each signal. The peak frequency in the range 3 to 10 Hz, which is known to contain the main atrial rhythm in fibrillation, was identified and compared for each of the techniques.

## 3. Results

### 3.1. Atrial signal extraction

Figure 1a shows a 6 s section of lead V1 from one of the patients and the atrial signals derived by each of the techniques. Atrial signals derived by the blind source separation technique are normalised for unit power, so in figure 1a the signal for this technique has been scaled to give a similar amplitude atrial component to the components from the other extraction techniques, for which amplitude information is preserved. All techniques substantially reduced the ventricular components of the ECG signal, although all techniques showed residual QRS components in some patients. In this example, the atrial signal derived by principal component analysis showed some breakthrough of the QRS wave into the atrial signal. As would be expected, the QRST cancellation applied to lead V1 produced an atrial signal which closely resembled the atrial signal seen in lead V1. The signals produced by blind source separation and principal component analysis combine information from all leads to derive the atrial signal, so a direct comparison with lead V1 should not be made. However, the atrial waveforms are similar in all cases and the additional frequency analysis of the extracted signals reveals their similarity.

### 3.2. Dominant atrial frequency

Frequency analysis was applied to the atrial signal derived from lead V1 using QRST cancellation for all patients. For blind source separation the greatest amplitude atrial signal occurred in signals 3 (1 patient), 7 (2 patients), 8 (1 patient), 9 (1 patient), 12 (2 patients). For principal component analysis the main atrial signal was found in principal component 4 (3 patients), 5 (2 patients) and 7 (2 patients) and these were the signals analysed.

Figure 1b shows the frequency spectra of the time domain signals shown in figure 1a. For this example it can be seen that the atrial signal had components ranging from approximately 5 to 8 Hz and this was the case for all techniques. There were differences in the location of the peaks of the spectra within this overall range. It can be seen from the spectrum of ECG lead V1 that it would be very difficult to accurately analyse the atrial rhythm without the use of some technique to remove the ventricular components. Table 1 provides details of the peak atrial frequencies for each atrial signal and ventricular rate for each patient. The three techniques showed good agreement with the maximum difference being 1 Hz (patient 1).

Table 1. Peak atrial frequencies for each technique and the ventricular rate for each patient (QRST = spatiotemporal QRST cancellation, BSS = blind source separation, PCA = principal component analysis).

| Patient | Ventricular frequency (Hz) | Atrial frequency (Hz) |     |     |
|---------|----------------------------|-----------------------|-----|-----|
|         |                            | QRST                  | BSS | PCA |
| 1       | 2.0                        | 7.6                   | 6.9 | 6.6 |
| 2       | 1.0                        | 5.9                   | 5.7 | 6.1 |
| 3       | 1.2                        | 6.2                   | 6.9 | 6.2 |
| 4       | 1.5                        | 6.4                   | 6.9 | 6.5 |
| 5       | 0.9                        | 7.5                   | 7.9 | 8.2 |
| 6       | 1.6                        | 5.9                   | 5.9 | 5.9 |
| 7       | 0.9                        | 6.2                   | 6.7 | 6.3 |
| mean    | 1.3                        | 6.5                   | 6.7 | 6.7 |

## 4. Discussion

The three atrial rhythm extraction techniques show good agreement in the estimated values of the fibrillatory frequency of the atrial rhythm despite differences in the derived atrial signals. Previous work has quantified the quality of the atrial signal in terms of how well the ventricular components have been removed [4]. Our focus here was to compare the techniques in terms of estimation of atrial frequency, since future work will aim to track changes in the frequencies of atrial rhythms during treatments for atrial fibrillation. Our results suggest that, for an analysis period of 60 s, the frequency analysis is resilient to imperfect removal of ventricular activity as even in cases where there were residual QRS waveforms there was close agreement. However, they may prevent the analysis of

shorter data sections.

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