# Time-Frequency Distribution Moments of Heart Rate Variability for Neonatal Seizure Detection

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## Abstract

In this paper, we propose features extracted from the heart rate variability (HRV) based on the first and second conditional moments of time-frequency distribution (TFD) as an additional guide for seizure detection in newborn. The features of HRV in the low frequency band (LF: 0-0.07 Hz), mid frequency band (MF: 0.07-0.15 Hz), and high frequency band (HF: 0.15-0.6 Hz) have been obtained by means of the time-frequency analysis using the Modified-B distribution (MBD). Results of ongoing time-frequency research are presented. Based on our preliminary results, the first conditional moment of HRV which is also known as the mean/central frequency in the LF band and the second conditional moment of HRV which is also known as the variance / instantaneous bandwidth (IB) in the HF band can be used as a good feature to discriminate the newborn seizure from the non-seizure.

## 1. Introduction

The newborn brain is particularly vulnerable to seizures which are associated with poor neurodevelopment outcome [1]. Currently, non-invasive detection of newborn seizure is made from the EEG. There is at present very little information on which clinicians can base a rational decision about treatment which is often ineffective and does not alter neurodevelopment outcome. Continuous monitoring of the newborn ECG and heart rate has been a successful alternative guide to detect the seizures [1]. In [2], the authors investigated rhythmic changes in ECG and heart rate to alert the physicians to the presence of seizures in 9 paralyzed infants. Experimental evidence in animal models suggests that changes in cardiac activity which accompany seizures are induced by a disruption of the normal autonomic control of the heart [2]. Methodologically similar studies in human neonate with seizure may not be practical, but the effects of these autonomic changes on cardiac activity would be detectable non-invasively by use of ECG [1].

The HRV is emerging as a major non-invasive tool in diagnostic and monitoring of the autonomous control as it is able to assess the state of the autonomic nervous system (ANS) [3]. The separate rhythmic contributions from sympathetic and parasympathetic autonomic activity modulate the heart rate, and thus the RR intervals of the QRS complex in the ECG, at distinct frequencies. Sympathetic activity in newborn is associated with the low frequency (LF) range (0.03–0.15Hz) while parasympathetic activity is associated with the higher frequency (HF) range (0.15–0.6Hz) of modulation frequencies of the heart rate. The mid frequency (MF), centers near 0.1 Hz, is both parasympathetically and sympathetically mediated. The HF corresponds to the respiratory and the LF mediated by a variety of different influences [4].

It was considered that the first and second conditional moment of TFD of the HRV signal in each one of the bands, would be good features in discriminating the seizure from the non-seizure newborn. A TFD that can provide high resolution in time and frequency domain is used to calculate the moments. The first conditional moment corresponds to the mean or central frequency of the respective spectrum of interest at a particular time and the second conditional moment corresponds to the variance or the instantaneous bandwidth (IB) [5]. In [6], it was reported that the TFD conditional moments can improve the performance of classification of non-stationary time series compared to those moments based on temporal or frequency alone

## 2. Conditional Moments of Time-Frequency Distribution

The general expression for the quadratic TFD is:

$$\rho_z(t,f) = \iiint e^{j2\pi(\nu t-\nu u-f\tau)} g(\nu,\tau) z(u+\frac{\tau}{2}) z^*(u-\frac{\tau}{2}) d\nu du d\tau \quad (1)$$

where *z(t)* is the analytic associate of the real signal *s(t)*. The function $g(\nu,\tau)$ is known as the TFD kernel and determines the characteristics of TFDs [7].The $n^{th}$ conditional moment of the TFD at time *t* is defined as:

$$f^n(t) = \frac{1}{P(t)} \int f^n \rho(t,f) df \quad (2)$$

where $P(t) = \int \rho(t,f) df$ (3)

The central/mean frequency and variance/IB can be defined as:

$$f_c(t) = \frac{1}{P(t)} \int f \rho(t,f) df \quad (4)$$

$$IB(t) = \frac{1}{P(t)} \int (f - f_c(t))^2 \rho(t,f) df \quad (5)$$

The central frequency is equivalent to the instantaneous frequency (IF) for the case of TFDs whose kernel satisfies the IF property [8]. This is not the case for MBD. Hence, the notion of IF is not of straightforward physical interpretation [7]. The variance provides an estimation of the instantaneous bandwidth. It represents the local spread in frequency for a given time, *t* [5]. In this study the two quantities are calculated from the MBD.

## 3. Method

The one channel newborn ECG was recorded simultaneously with 20 channel EEG. The EEG was labeled as either seizure or non-seizure by a neurologist from the Royal Children's Hospital, Brisbane, Australia. In the present study we analysed 6 seizure event and 4 non-seizure event from 5 different newborns. All of them ranging from 2 days to 2 months old. The proposed methodology includes the following steps:

a) The original ECG signal was pre-processed using the 8-15 Hz bandpass filter. The filter reduces noise in the ECG signal by matching the spectrum of the average QRS complex [9].

b) The smoothed nonlinear energy operator (SNEO) was used for detecting the beat-to-beat values of R-R interval [10]. The trends of the time series were computed and removed to remove artifacts which would mask the frequencies of interest.The resulting time series is called tachogram, a sequence of unevenly sampled beat-to-beat intervals. To make the data evenly sampled, cubic splines interpolation at sampling rate of 2 Hz was employed.

c) Three band-pass FIR filters have been applied to the signal. The selected band-pass frequencies are 0-0.07 Hz (LF), 0.07-0.15 Hz (MF) and 0.15-0.6 Hz (HF).

d) For each seizure and non-seizure events, the TFD was applied to three filtered signals. Previous works have shown that MBD outperforms other existing distributions in terms of time-frequency resolution, as well as cross-terms suppression when representing newborn HRV [11].Thus the MBD will be used here to extract the 2 moments from HRV to be used as features to distinguish the non-seizure and seizure babies. The kernel for MBD is $g(\nu,\tau) = |\Gamma(\beta + j\pi\nu)|^2 / \Gamma^2(\beta)$ where $\beta$ is a real, positive number that controls the trade off between components' resolution and cross-terms suppression and $\Gamma(.)$ stands for the gamma function [7]. The parameter, $\beta$ of its kernel was set to 0.0001. Figure 1 shows the TFD of HRV related to (a) seizure and (b) non-seizure.

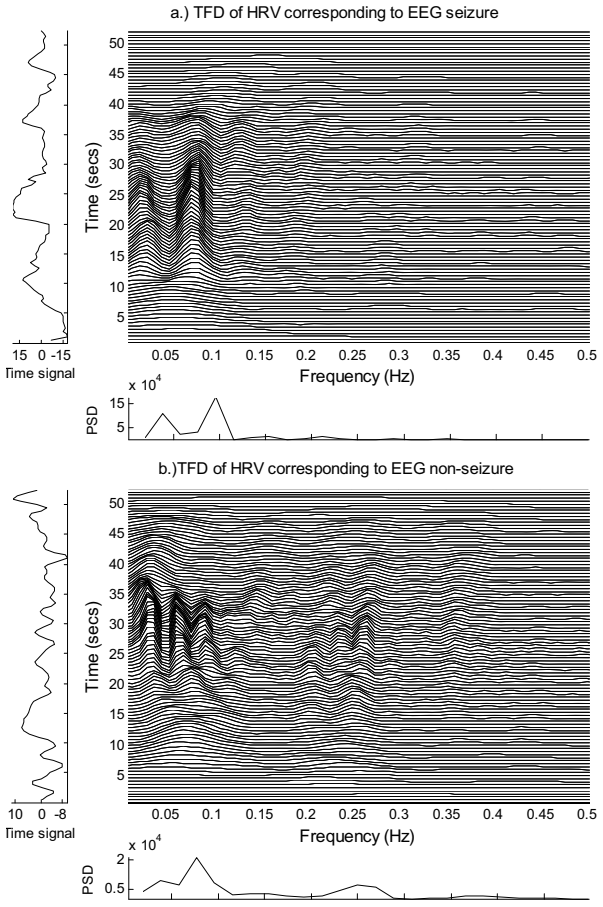



**Figure 1:** TFD of HRV corresponding to (a).EEG seizure and (b).EEG non-seizure.

e) The $f_c(t)$ and $IB(t)$ were found using the MBD. To avoid the influence of the boarder effects introduced by the filters and window used in the TFD, the two time-varying moments in each band are shortened. The central frequency and IB of LF, MF and HF for the (a) seizure and (b) non-seizure EEG are shown in Figure 2 and 3 respectively.

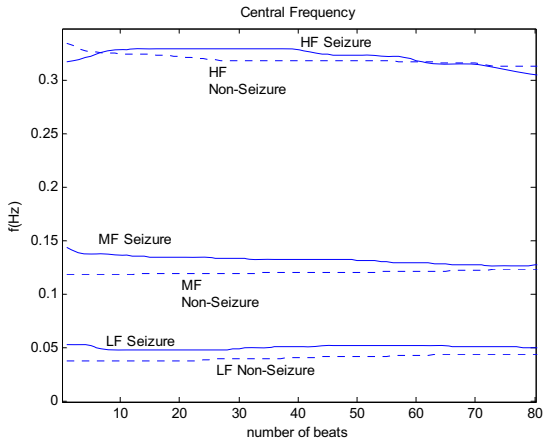



**Figure 2**: The central/mean frequency of the LF, MF and HF of HRV related to EEG seizure (solid) and EEG no-seizure (dashed).

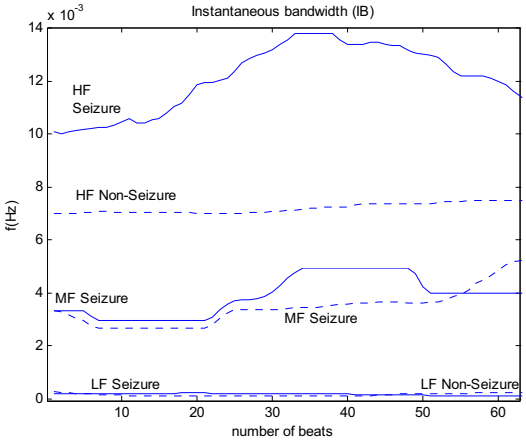



**Figure 3**: The IB of the LF, MF and HF of HRV related to EEG seizure (solid) and EEG no-seizure (dashed).

## 4. Performance Evaluation and Discussion

The classification performance of the central frequency and IB metrics are assessed using the leave-one-out (LOO) cross-validation. For 9 events at a time, the central frequency values for seizure were compared with those from non-seizure events, and a threshold was chosen that best differentiated the two groups on the basis of a receiver-operating characteristic (ROC) curve. This threshold was then compared with the central frequency of the one patient not included in the group of 9, and the classification success noted. The procedure was applied 10 times for both central frequency and IB in all 3 frequency bands, since there were 10 events. The results of the tests were used to calculate the sensitivity, $R_{sn}$ and specificity, $R_{sp}$ of the methodology for all 3 frequency bands. The sensitivity, $R_{sn}$ and specificity, $R_{sp}$ are defined as below.

$$R_{sn} = \frac{TP}{TP + FN} \quad ; R_{sp} = 1 - \frac{FP}{TP + FP} \qquad (5)$$

where *TP*, *FN*, and *FP* respectively represent true positive, false negative and false positive detection rates. Table 1 shows the results for central/mean frequency feature while Table 2 shows the results for the IB feature.

Table 1: Results for the central/mean frequency.

| Frequency Band | $R_{sn}$ | $R_{sp}$ |
|---|---|---|
| LF | 83.33% | 100.00% |
| MF | 83.33% | 66.67% |
| HF | 50.00% | 16.67% |

Table 2: Results for the Instantaneous Bandwidth (IB).

| Frequency Band | $R_{sn}$ | $R_{sp}$ |
|---|---|---|
| LF | 66.67% | 66.67% |
| MF | 83.33% | 66.67% |
| HF | 83.33% | 100.00% |

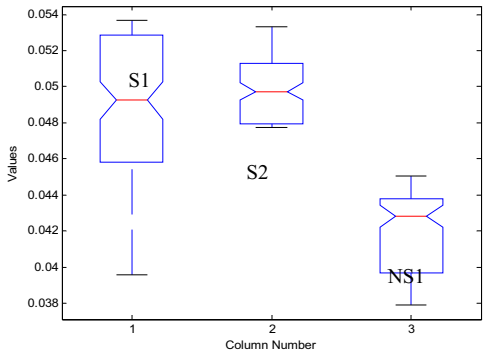
From Table 1, it can be seen that the seizure can be discriminated the best from the non-seizure using the central frequency features from the LF band which gives 83.33% of sensitivity and 100% of specificity. The optimal threshold to differentiate the seizure from the non-seizure was found to be 0.0453 Hz. This indicates that the newborn seizure has effect in the LF component (sympathetic activity) of the HRV the most compared to the MF and HF. The MF component has greater effect than HF because it is both parasympathetically and sympathetically mediated. The central frequency features from the HF band shows very poor performance. This brings to a conclusion that the seizures have the least effect in the parasympathetic activity. Another reason that leads to the poor performance could be because the features suffered from a degree of patient-dependence and the seizure activities from one newborn itself has different characteristics. This can be noted from the boxplots shown in Figure 4.

These boxplots are plotted for a newborn which has 2 seizure events, S1, S2 and a non-seizure, NS1 event for (a.) LF band, (b.) MF band and (c.) HF band. From the boxplots in the HF band, S1 and S2 have different statistical characteristics. Since the notches in the boxplot do not overlap, it can be conclude, with 95% confidence that the true medians between the two do differ.

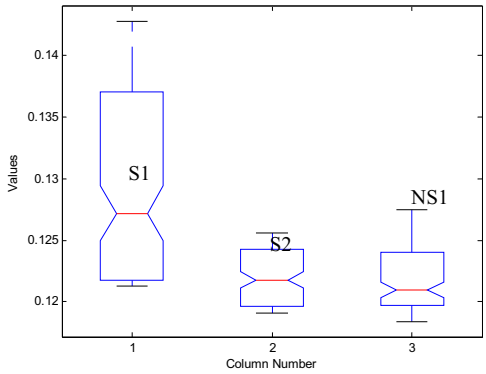
As for the IB, as can be seen in Table 2, the non-seizure can be discriminated clearly from the seizure in the HF band which results 83.33% of sensitivity and 100% of specificity. The optimal threshold found was 0.0033 Hz. This shows that the variance of the frequency in the HF has been affected greatly by the newborn seizure. This could be because of the greater variation in the respiratory of the newborns during seizure. It is worth noting that the central frequency in the HF shows insignificant difference between the seizure and non-

seizure but the spread of the frequency in the HF band shows significant difference between them. The IB from the LF and MF band did not show considerable changes. Thus, those features are not efficient to be used as a parameter to classify seizure and non-seizure.

(a) LF




(b) MF




(c) HF

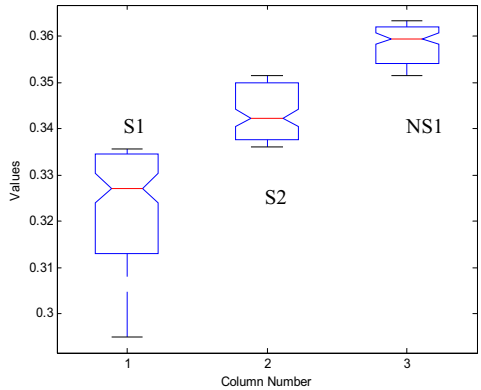



**Figure 4:** Boxplots for a newborn which has 2 seizure events, S1, S2 and a non-seizure event, NS1 for (a.) LF band, (b.) MF band and (c.) HF band.

The motivation for examining the variability of central frequency and IB is to identify autonomic instability, rather than assess the magnitude of particular spectral bands. The hypothesis is that newborns with greater variability in their central frequency and IB in the LF band and HF band respectively might experience seizure and this information can be used as an additional guide for seizure detection in newborn.

## 5. Conclusion

These are the results of our ongoing study. Based on our preliminary results, the mean/central frequency from the LF band and the IB from the HF band originated from the first and second conditional moment of HRV based on MBD can be used as a good feature to discriminate the newborn seizure from the non-seizure. The future research will be focused on applying the methodology on larger number of newborns and obtain numerical parameters for classification.

## 6. Reference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