35th Annual International Conference of the IEEE EMBS
Osaka, Japan, 3 - 7 July, 2013

Higher Order Spectral Analysis of Heart Rate Variability in Pregnancy and Postpartum

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Abstract— **This paper presents the study of bispectrum analysis methods of heart rate variability in normotensive pregnant and postpartum women. The self and cross spectral components are estimated from bispectrum of ECG of pregnant and postpartum women. It is observed that, very low frequency (VLF) and low frequency (LF) component coupling increases while the high frequency (HF) coupling and cross coupling between VLF-LF, VLF-HF and LF-HF decreases throughout the pregnancy. The power at very high frequencies decreases as gestation age progresses. Significant differences are found in similar and cross coupling frequency components in all three trimesters and postpartum. The results indicate that one possible discriminating dynamics for the pregnant women in all three trimesters is the absence of nonlinear interactions between the sympathetic and parasympathetic nervous systems.**

Keywords: electrocardiography, heart rate variability, bispectrum, pregnancy.

I. Introduction

Normal pregnancy is associated with hemodynamic and cardiovascular changes. The physiological adaptation including an increase in heart rate, stroke volume and cardiac output and decrease in blood pressure and vascular resistance. The action of autonomic nervous system is thought to be important for the maternal adaptations, but its role is not fully understood [1] [2]. Autonomic function can be assessed by means of heart rate variability. It was reported that, both low and high frequency components of HRV were significantly lower in pregnant women as compared to non-pregnant women [3]. It was shown that the sympathetic activity remains unchanged in the first trimester of pregnancy [2]. It was reported that the sympathetic activity increases during normal pregnancy and decreases in case of threatened preterm delivery and immediately before normal delivery [4] [5].

In the frequency domain, the power spectrum was estimated by parametric or nonparametric methods. The power spectrum divided in very low frequency (VLF) low frequency (LF) and high frequency (HF) with frequency band of 0.0033-0.04 Hz, 0.04-0.15 Hz and 0.15-0.4 Hz respectively. The LF is attributed to the actions of both sympathetic and parasympathetic nervous activities, whereas the HF is solely due to the parasympathetic nervous activities. The LF and HF were measured in normalized units where the absolute value of each power component is expressed as a proportion of total power. The normalized units emphasise the controlled and balanced behavior of the two branches of the autonomic nervous system. In general the HRV signal might contain phase-coupled harmonics, nonlinear random components and a mixture of the two. The nonlinear interaction can be identified in many forms such as entropy methods and phase coherence. The spectral measures do not reflect changes in stationarity or the number of independent pacemakers in a complex system, then complete assessment of HRV includes non-linear measures [6] [7].

To investigate the time varying spectral characteristics of the underlying process, most of the methods often begin by computing the time variation of the common statistical properties of the process. In practice the ECG, pulse and other physiological signals show significant non-stationary and non-Gaussian characteristics due to the presence of non-linear effects of phase coupling among the signal frequency components. The power spectral methods fail to describe the phase relationship between the frequency components of HRV signals while bispectrum analysis provides complete information including phase, when HRV is nonlinear and non-Gaussian. Bispectrum also provides nonlinear interaction between the frequency components of the HRV signals [8].

The ECG signals are used to study the heart rate variability analysis during different phases of pregnancy and postpartum state using bispectrum. In this paper we present the self similar spectrum and cross spectrum parameters to analyze HRV in postpartum, 1^{st} trimester, 2^{nd} trimester and 3^{rd} trimester of the pregnancy group.

II. Subjects

We performed a cross sectional study involving 25 subjects in the first trimester, 47 in second trimester, 52 in third trimester of pregnancy and 32 women in postpartum (within a week). The subjects were consented from the routine antenatal clinic and hospital staff who agreed to participate. All pregnant women had normal pregnancy. The parameters like maternal age, weight, blood pressure status were recorded. This study was cleared and approved by the bioethical committee. Further all women gave written informed consent for collection of data. The demographic characteristics of the study population are presented in Table I.

*Authors wish to thank District Health and Family Welfare officer Davanagere for their support. The support extended by Dr. Chandrakala Medical Officer and staff, Maternity centre, Bhashanagara, Davanagere during data collection is also thankfully acknowledged.

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TABLE I

DEMOGRAPHIC CHARACTERISTICS OF THE STUDY POPULATION

Parameters	I	II	III	Postpartum
Age (years)	23.11± 2.961	22.09± 2.296	23.06± 2.867	23.74± 2.661
Weight (kgs) (kgs)	45.57± 6.801	47.54± 5.316	52.47± 6.458	44.12± 2.736
Gestational age (weeks)	10.8± 2.203	20.4± 3.125	32.38± 3.024	2.476± 1.721(days)
SBP (mmhg)	116± 8.137	116.1± 7.324	115.7± 7.503	118.4± 5.448
DBP (mmhg)	76.1± 5.61	75.02± 7.492	74.49± 7.409	77.97 ± 4.601

III. DATA ANALYSIS AND METHODS

ECG signals were recorded under normal breathing conditions using National Instrument's data acquisition card and signal express software from Labview. The signals are recorded at a sampling frequency of 500 Hz with a resolution of 12 bits per sample. The HRV was calculated by measuring the RR interval.

For real time, zero mean process x(n), the third order cumulants are identical to third order moments [9]. These cumulants are defined as

$$c_{xxx}(m_1, m_2) = E[x(n)x(n+m_1)x(n+m_2)] \quad (1)$$

Where E [.] denotes the expectation operator. The bispectrum is the two dimensional discrete Fourier transform of the third order cumulant. The bispectrum is as follows

$$B_{xxx}(f_1, f_2) = \sum_{m_1=-\infty}^{+\infty} \sum_{m_2=-\infty}^{+\infty} c_{xxx}(m_1, m_2) e^{-j(f_1 m_1 + f_2 m_2)} \quad (2)$$

In the above definitions, the Fourier representation of the cumulant functions satisfy the conditions $|f_1| \leq \pi, |f_2| \leq \pi$ and $|f_1 + f_2| \leq \pi$. The cumulants of random process is deterministic and then bispectrum are determined as a triple product of discrete Fourier transforms instead of two-dimensional discrete Fourier transforms at discrete frequencies f_1, f_2 and $f_1 + f_2$. The bispectrum is a function of two discrete frequencies f_1 and f_2. The frequency may be normalized by the Nyquist frequency to be between 0 and 1. The estimation results are all based on the direct method of computing the bispectrum. This approach which statistically quantifies the presence of phase coupling equally applies to both indirect and parametric based method of estimating the bispectrum [9] [10].

$$B_{xxx}(f_1, f_2) = X(f_1)X(f_2)X^*(f_1 + f_2) \quad (3)$$

The bispectrum was estimated from RR intervals of single record by direct method. The VLF, LF, HF and OF are chosen based on power spectral density indices on both the axes. The frequency above 0.4 Hz is referred as other frequency (OF) region, which is also known as nonlinear region. The magnitude of the bispectrum was distributed along the diagonal of bifrequency plane with coordinates VLF-VLF (VS), VLF-LF (VLC), VLF-HF (VHC), VLF-OF (VOC), LF-LF (LS), LF-HF (LHC), LF-OF (LOC), HF-HF (HS), HF-OF (HOC) and OF-OF (OS) as shown in Fig. 1. The components VS, LS, HS and OS are self spectral components and others are cross spectral components [11].

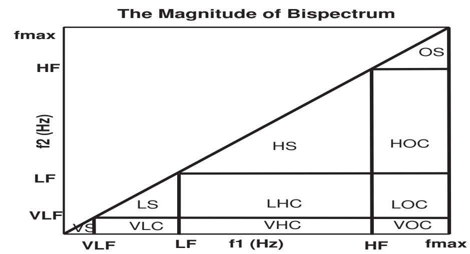

Fig. 1. The magnitude of bispectrum in first quadrant

IV. RESULTS

The heart rate of 75.25 ± 7.331, 91.44 ± 7.315, 93.34 ± 6.812 and 100.8 ± 10.12 beats per minute were observed in postpartum, I, II and III trimester respectively. The heart rate varied significantly during the pregnancy as gestation age progressed ($p \leq 0.001$). The variation of self and cross coupling parameters of all the subjects with mean ± SD are as shown in Fig. 2. The mean and SD of self and cross spectral frequency components from pregnant women and postpartum women are presented in Table II. For the statistical analysis, we used ANOVA test to discriminate among the means of the three trimesters and postpartum groups. The significant decrease in phase coupling between VLF-VLF (7.348 ± 2.595 vs. 22.96 ± 6.642), VLF-LF (9.685 ± 4.105 vs. 24.97 ± 3.4931) and LF-LF (7.668 ± 2.43 vs. 18.06 ± 4.285) is observed in the postpartum women as compared to the III trimester pregnant women. LF-HF (19.57 ± 4.243 vs. 11.16 ± 4.773), HF-HF (20.04 ± 5.192 vs. 6.137 ± 2.193) and TOF (22.54 ± 4.38 vs. 6.497 ± 2.917) increased significantly immediately after the delivery as compared to III trimester pregnant women. The variation of the mean is summarized in Fig. 3 and it is seen that VS, VLC and LS increases while VHC, LHC and HS decreases during the pregnancy. The power at very high frequency (10.261 ± 4.644, 6.6983 ± 1.916 and 6.497 ± 2.917 in I, II and III trimester respectively) components decreases as pregnancy progresses. The LS/HS ratio is significantly increased from I trimester and reaches maximum at III trimester (1.621 ± 0.4022, 1.854 ± 0.663 and 2.54 ± 1.143 in I, II and III trimester respectively) and this ratio is significantly decreased to (0.5362 ± 0.1203) immediately after delivery. The range, median and quartile of the LS/HS ratio are depicted in Fig. 4.

V. DISCUSSIONS

The magnitude of the bispectrum in nonlinear region is diminished for the lower complex and dynamic HRV signals. The magnitudes of the bispectrum for pregnant and postpartum group are as shown in Fig. 5. The coupling at LF and LF (LS) may represent one of three possible scenarios: sympathetic self coupling or parasympathetic self coupling or

TABLE II

MEAN AND SD OF BISPECTRAL SELF AND CROSS SPECTRAL COMPONENTS

Parameters	VS	VLC	VHC	LS	LHC	HS	TOF§
I Trimester	13.73 ± 3.603	20.88 ± 3.142	13.04 ± 3.142	16.6 ± 4.246	16.63 ± 4.112	9.636 ± 2.043	10.261 ± 4.644
II Trimester	9.664 ± 3.769	16.55 ± 4.218	12.56 ± 3.578	23.06 ± 3.494	17.34 ± 3.238	14.12 ± 2.678	6.6983 ± 1.916
III Trimester	22.96 ± 6.642	24.97 ± 3.4931	10.28 ± 3.475	18.06 ± 4.285	11.16 ± 4.773	6.137 ± 2.193	6.497 ± 2.917
Postpartum	7.348 ± 2.595	9.685 ± 4.105	13.22 ± 2.593	7.668 ± 2.43	19.57 ± 4.243	20.04 ± 5.192	22.54 ± 4.38

§ - TOF is the sum of all other frequency component(VOC+LOC+HOC+OS).

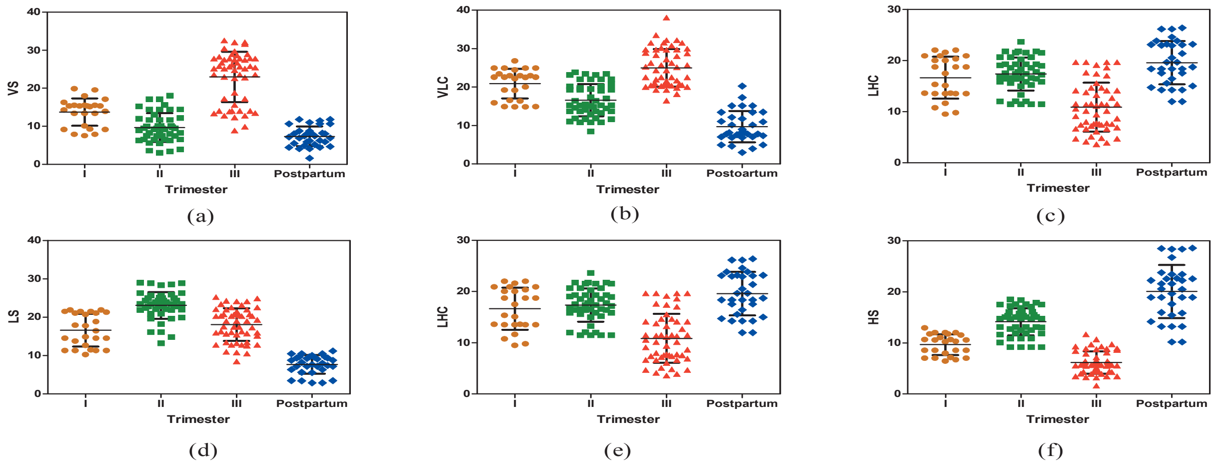

Fig. 2. The %age power of self and cross spectral components with Mean and SD of all the subjects in different group

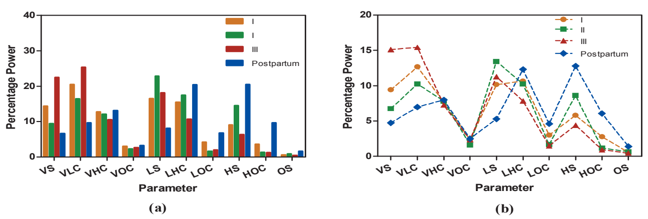

Fig. 3. The comparison of mean values of the bispectral self and cross spectral components in I, II and III trimester pregnant and postpartum women

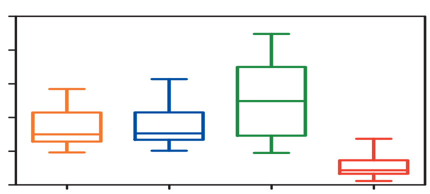

Fig. 4. The minimum, maximum, median and quartiles of the LS/HS ratio

sympathetic and parasympathetic interactions. A peak at HF and HF (HS) represents a self coupling of parasympathetic nervous activities [12]. During the postpartum, the significant nonlinear interactions between sympathetic and parasympathetic activities as compared to III trimester, further the increased VHC (13.22 ± 2.593 vs. 10.28 ± 3.475), LHC (19.57 ± 4.243 vs. 11.16 ± 4.773), HS (20.04 ± 5.192 vs. 6.137 ± 2.193) and TOF (22.54 ± 4.38 vs. 6.497 ± 2.917) coupling components are seen. The postpartum group exhibits the higher amount of interactions at VHC, LHC, HS and TOF frequencies whereas lower coupling is observed in pregnant group as shown in Fig.5. The HS and LHC coupling is higher in postpartum group and LS and VLC are higher in pregnant group.

Further, nonlinear phase couplings were observed between LF and HF oscillations of HRV. Nonlinear interactions between the sympathetic and parasympathetic nervous activities were found in both pregnant and postpartum group. Further it was observed from Fig. 5, that there is a significant nonlinear coupling in the postpartum group as compared to the pregnant group. This inferred that, the sympathetic tone is enhanced for the pregnant women as gestation age progresses. Also higher nonlinear coupling was seen between the VLF, LF and HF in postpartum women. It was reported that the decreasing levels of muscle sympathetic nerve activities (MSNA) were associated with a shift of spectral power toward the HF component. Further these results agree with the other studies carried out in MSNA [11].

Similar to power spectral components in frequency domain, the LS coupling may indicate interactions between either the sympathetic activity itself or the sympathetic and parasympathetic nervous activities. The HS represents parasympathetic activity self-coupling, given the fact that the presence of sympathetic nervous regulation is rather small in the HF bands. The LHC may indicate both parasympathetic self-coupling or sympathetic and parasympathetic nervous system interactions. The bispectral analysis provides evidence of the presence of nonlinear interactions in the data. We observed that decreased phase coupling during III trimester in LHC and HS as compared to I and II trimester while it increases immediately after the delivery. Further it is

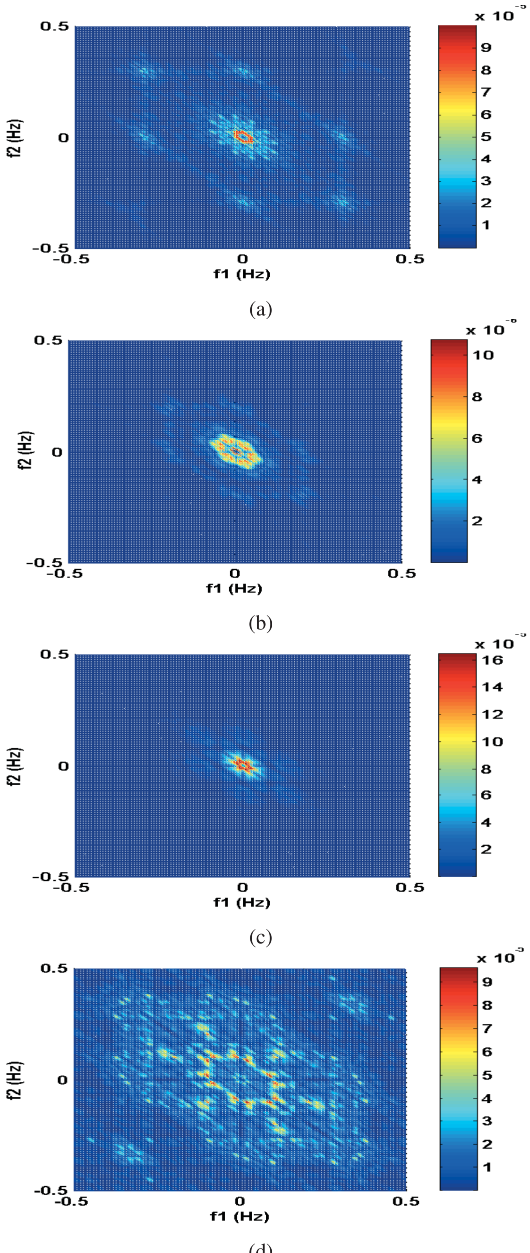

Fig. 5. The responses of the magnitude of bispectrum in (a) I Trimester (b) II Trimester (c) III Trimester (d) Postpartum

observed that the interactions between the sympathetic and parasympathetic nervous activities in normotensive pregnant women reduces. It is interesting to note that as pregnancy progresses, the parasympathetic activity decreases and minimizes the presence of LHC and other frequency components. These findings can be interpreted as an indication of the important role played by the parasympathetic nervous system within HRV in maternal conditions. This interpretation is the involvement of the vagal component of the autonomic nervous system in producing nonlinear dynamics in the heart rate. Further we found the LHC coupling decreases in the pregnant women with progressed gestation age as compared to postpartum women. These results hold similarly for the HS coupling, which was greatly reduced in third trimester compared with either I and II trimester or immediately after the delivery. The power at very high frequency decreases as pregnancy progresses. This implies that the complexity in HRV signal is reduced due to sympathetic stimulation during pregnancy.

VI. Conclusion

This study suggests that, the bispectrum is determining the presence of nonlinear coupling between sympathetic and parasympathetic activities. Our results indicate that one possible discriminating dynamics for the pregnant women in all three trimesters is the absence of nonlinear interactions between the sympathetic and parasympathetic nervous systems, which is likely to reflect the reduced vagal tone during the pregnancy. The study further suggests that the parasympathetic activity increases due to discharge of vagal tone immediately after delivery. It is shown that the changes in the HRV signifies that the sympathetic activity of the autonomic nervous system in normal pregnancy increases and decreases immediately after delivery. The VS, VLC, LS, HS and LS/HS ratio may be used to quantify the HRV to discriminate different stages of pregnancy. Further longitudinal studies are needed to demonstrate weather this approach can be used to quantify the HRV in pregnant and postpartum women.

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