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Phase Synchronization analysis of Heart Rate Variability and Systolic Blood Pressure Variability under Postural Stress

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Abstract: **In this paper, the coupling between heart rate variability (HRV) and systolic blood pressure variability is analyzed using a non-linear measure called phase synchronization index (PSI). 20 healthy subjects alongwith 20 post myocardial patients undergong postural stress were used for analysis. The results were validated on standard EuroBaVar dataset. Results demonstrate that i) for healthy subjects PSI in the low frequency (LF) range i.e. (0.04-0.15) Hz is greater than PSI in the high frequency (HF) range i.e. (0.151-0.4) Hz in the lying position. ii) LF-PSI is less than HF-PSI in the standing position ii) for post AMI patients, LF-PSI is greater than HF-PSI irrespective of the change in posture. In conclusion, it is found that there is a coupling between HRV and SBPV that varies in the LF and HF regions. This coupling changes with a change in the posture from lying to standing due to change in the autonomous drive occurring due to predominance of vagal over the sympathetic drive. This change is suppressed in the post AMI patients due to possible inactivity of the Baroreflex control.**

Index Terms— **autonomic nervous system, heart rate variability, systolic blood pressure variability, phase synchronization, coupling, baroreflex**

I. INTRODUCTION

Reflex and non-reflex procedures functioning at diverse time scales are accountable for beat-to-beat oscillations of cardiovascular variables aiming at conserving the rhythmical deviations within safe limits. Physiologically, heart period (HP) which is the time interval between two successive R-peaks (RR) affects systolic blood pressure (SBP) both due to feedback (FB) loop of baroreflex and collective result of Starling's law and diastolic runoff in a feed-forward (FF) means. Prevailing causal direction is decided by the predominant mechanism. It is well established that the study of cardiovascular interactions may decipher the functioning of the autonomic nervous system (ANS) [1]; the contributing variables are HP and SBP. These variables possess a cause and effect relationship. These baroreflex and non-baroreflex mechanisms characterize the status of ANS. To investigate the coupling between RR interval and SBP variability series, cross spectral analysis has been widely used by various researchers [2,3,4,5,6,7,8,9,10,11]. The capability of spectral methods is limited to decipher the linear unidirectional interactions between RR and SBP with emphases on estimation of spontaneous baroreflex which occurs due change in SBP causing a subsequent change in RR interval. Indeed, physiologically the interactions between RR and SBP are bidirectional with involvement of baroreflex FB as well as mechanical FF coupling mechanisms. The assumption of these spectral methods that causal direction is from SBP to RR may produce misleading results. Physiological mechanisms which govern RR-SBP causal interactions make it of prime importance to quantify the two reverse interactions. The dominant causal direction out of RR→SBP and SBP→RR tells us the physiological mechanism involved i.e. whether the coupling is due to diastolic runoff and Starling's law or a regulatory baroreflex FB. The phase synchronization of coupled systems is defined as the appearance of certain relation between their phases, while the amplitudes can remain non-correlated. This paper employs a non-linear method like phase synchronization that starts with detection of phases of respective signals by any of the phase estimation methods. n:m phase synchronization can be found by setting integers values or n and m. Phase synchronization in multiple temporal scales [18] can be obtained by using different integer values for n and m. Constant value of difference between the instantaneous phases gives the synchronization epochs where the two time series are synchronized. The ratio of the instantaneous frequency can also be evaluated. Since, cardiovascular dynamics may have interactions at different temporal scales multiple values of phase synchronization index can be found to look for synchronization regimes between the HRV and SPBV. Both

LF and HF PSI is computed for healthy as well as post AMI patients undergoing postural stress from lying to standing.

II. METHODS

A. Data collection:

We studied 20 control (healthy) subjects (ages 21-32 yr, median age 26) with no past record of any disease. They were refrained from taking any medication, caffeinated and alcoholic beverage at least 24-hr from the time of recording. The recordings were performed in a quiet room. Spontaneous breathing was ensured during the recording. The control subjects were initially made to rest for 10 minutes before recording was performed for supine and upright positions. The study followed the practice followed in EuroBaVaR study, i.e., recording during supine and standing postures. Electrocardiogram (ECG) and noninvasive continuous blood pressure (BP) signal was recorded for these 42 subjects using MP100 Biopac© System. Data for postural stress test was recorded for 20 mins for both supine and standing conditions with a 3 minute pause between the two positions at a sampling rate of 500Hz. The same procedure was followed for a separate set of 20 post AMI patients.

B. Extraction of beat-to-beat variability series

QRS complex on the ECG was detected to locate the R-peaks using an algorithm based on empirical mode decomposition (EMD) [20]. Systolic blood pressure (SBP) values were also located using the same algorithm. SBP and R-peaks occurrences were carefully checked. Any presence of ectopic beats was removed using linear interpolation. From the detected peaks of both ECG and BP signal, time series of RR intervals and SBP values is formed. RR interval series and Systolic peaks' series thus obtained are functions number of heartbeats rather than occurrence time. The SBP and RRI were mean subtracted. Beat-to-beat SBP and RRI series are considered for each subject. 512 samples of RR intervals and Systolic pressure values are considered for analysis from both EuroBaVaR data as well as recorded data. Since, RR intervals are non-uniformly spaced a pre-processing technique adopted in [20] is used to obtain new RR interval series.

C. Phase Synchronization Index (PSI)

If ϕ_1 and ϕ_2 are the phases of two time series, the general n to m phase synchronization can be found if

$$\left[\Delta\phi_{n,m}-\phi_0\right]\bmod 2\pi=\left[\left(n\phi_1-m\phi_2\right)-\phi_0\right]\bmod 2\pi<2\varepsilon \qquad (1)$$

with $0 < \varepsilon = \pi$ holds – notice that the phase is a circular variable.

III. RESULTS AND DISCUSSION

Figure 1 and 2 shows the LF and HF PSI calculated using equation (1) for subjects of EuroBaVar dataset in lying and standing postures respectively. The results depicted are for each of the subjects from the dataset. The results were also obtained for 20 healthy control subjects along-with 20 post AMI patients subject to postural change from supine to standing. Table 1 and Table 2 shows the results obtained along-with significance level $p<0.05$. LF and HF PSI results are depicted using mean and SD. The significance of difference between LF and HF PSI is also found. Further, the significance of difference between lying LF and HF PSI and standing LF and HF PSI is also calculated.

It is observed from the Figures 1 and 2 that LF-PSI is more than HF PSI for lying as well as standing postures. This indicates the predominance of coupling between HRV and SBPV in the LF region than that of HF region. In other words, coupling in the LF region is stronger than the HF region. Table 1 and Table 2 shows that lying LF PSI is greater than the standing LF PSI indicated stronger coupling in the lying posture in the healthy subjects. On the other hand, for post AMI patients significant change in coupling from lying to standing is missing which physiologically indicates lack of

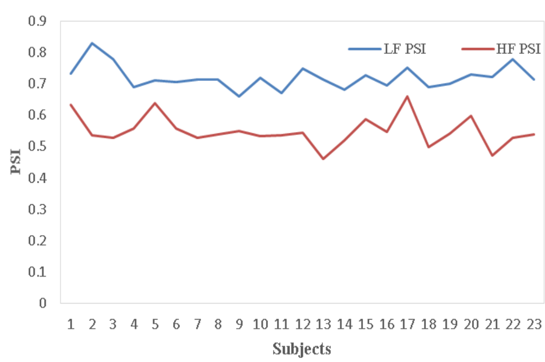

Figure 1: LF and HF PSI of subjects from EuroBaVaR dataset in lying posture

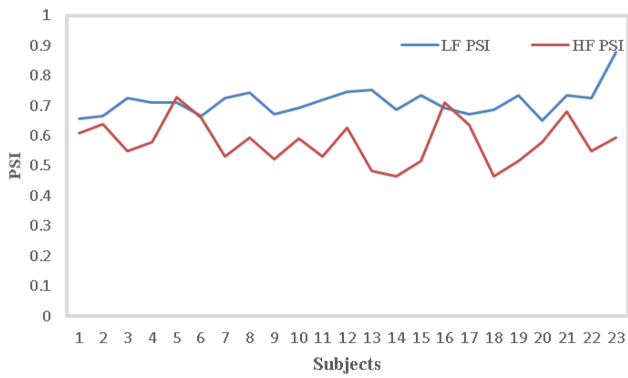

Figure 2: LF and HF PSI of subjects from EuroBaVaR dataset in standing posture

Table 1: Mean and SD of LF-PSI in lying and standing posture with significance level p<0.05

Posture	**HF-PSI (Mean±SD) Lying**	**HF-PSI (Mean±SD) Standing**	**p-value**
Healthy	0.549±0.047	0.580±0.073	0.021
Post AMI patients	0.489±0.159	0.047±0.042	0.037
p-value	0.032	0.026	-

Table 2: Mean and SD of HF-PSI in lying and standing posture with significance level p<0.05

Posture	**LF-PSI (Mean±SD) Lying**	**LF-PSI (Mean±SD) Standing**	**p-value**
Healthy	0.720±0.037	0.714±0.042	0.032
Post AMI patients	0.492±0.013	0.466±0.011	0.053
p-value	0.021	0.035	-

Bar reflex control. Moreover, there is also a significant decrease in coupling index i.e. both LF-PSI and HF PSI from healthy subjects and patients of post AMI. Table 2 shows the similar results for standing posture.

IV. CONCLUSION

This paper focusses on finding the coupling between HRV and SBPV under postural stress from lying to standing. For this a non-linear method based on n:m phase synchronization is employed. It is found that the coupling between the two variabilities varies in the LF and HF region of autonomic frequency range. There is also a variation in the coupling indicated by change in PSI as a result of posture change from supine to standing. Physiologically, this indicated the predominance of vagal autonomic drive over the sympathetic drive. The method based on the phase synchronization for analysis of coupling is more effective as it takes into account the non-linear nature of cardiovascular interactions between HRV and SBPV.

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