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Time-Evolution of Cardiovascular Variability During Autonomic Function Tests in Physiological Investigations

Dilbag Singh, B. S. Saini, Vinod Kumar, *Senior Member, IEEE*, and Kishore K. Deepak

***Abstract*—Autonomic function testing forms an integral part of physiological investigations both for human and animal research. Clinically, recent times have seen them emerging as tools in settling diagnosis in several neurological, cardiovascular, endocrinal disorders where autonomic function are compromised. The reasons for such emergence have been their simplicity, noninvasiveness, and their ability to decipher the control systems. A time-varying spectrum estimation method for analyzing heart rate variability signals dynamics is presented. As a case study, the dynamics of heart rate variability during autonomic function tests is examined using wavelets. The obtained spectrum estimates have further been decomposed into separate components and, thus, the time variation of low and high frequency components of heart rate variability can be examined separately. Thus, the present study aims to ascertain the association between heart rate changes and HRV parameters. The wavelet based HRV analysis has been found to faithfully represent the sympathovagal balance during standard autonomic battery test.**

I. Introduction

THE ruling action of the autonomic nervous system (ANS) controls is not static. Due to this dynamic action, the physiological parameters do not remain in the same stationary status but are modified by the evolving condition of the cardiovascular regulatory systems [1]. Applications of conventional spectral approaches, such as Fourier transform (FT) or autoregressive (AR) model, to HRV analysis, thus, always remain problematic since they are applied based on the assumption of stationarity [2], [3]. Also capturing hidden dynamics in both healthy and chronically ill subjects could yield important insights into understanding physiological mechanisms. Heart rate variability (HRV) analysis is complicated by the fact that these signals are typically both highly irregular and nonstationary i.e., their statistical character changes slowly or intermittently as a result of variations in background influences. FT and AR methods have served a critical role in the understanding of basal autonomic cardiac control. However, these algorithms have limitations in the study of heart rate for nonlinear variations and transient alterations. Recently, Wavelet Transform (WT) has been shown to provide separately the time evolution of the different frequency components of HRV signals [4] – [6]. Here, WT based analysis with emphasis on the time evolution of the different frequency components of HRV signal and sympathovagal balance has been shown to monitor ANS adaptations induced by physiological interventions in beat-to-beat intervals when different experimental protocols are used. The procedure was applied to quantify the time evolution of HRV parameters under steady state and to identify subperiods of steady state during a sequence of physical activities. Results showed the capability of proposed techniques to provide additional practical diagnostic and prognostic insight by mapping autonomic abnormalities.

In this work, a study of ECG records to evaluate the possibility of analysis of heart rate variability with the wavelet transform with emphasis on the time evolution of the different frequency components of HRV signal. The ability of this technique to track separately the time evolution of the different frequency components and more effective quantification of time varying changes of HRV signals have been demonstrated. Therefore our aims were threefold: first to investigate the effectiveness in inducing RR interval changes of 4 autonomic function tests, second to investigate effect that these 4 tests have on HRV, and third to investigate the offset and recovery of sympathovagal balance in pretest and post-test periods respectively.

II. Materials and Methods

A. Subjects and Data Collection

ECG recordings were made from five healthy young subjects, which were free from diabetes mellitus, hypertension, alcohol dependence, and other diseases that can affect autonomic function. The vital signs of subjects such as temperature, pulse and blood pressure were checked for any abnormality. Further the selected subjects were free from the presence of any autonomic symptoms *e.g.*, excessive sweating, constipation, loose motion, impotence, syncopal attacks, and

Dilbag Singh and B. S. Saini are with the Instrumentation & Control Engineering Dept. and Electronics & Communication Engineering Dept. respectively, Dr. B. R. Ambedkar National Institute of Technology, Jalandhar – 144 011, Punjab INDIA (corresponding author, phone: +91-98884 92132; fax: + 91-181-2690932;e-mail: singhd@nitj.ac.in).

Vinod Kumar is with the Electrical Engineering Department, Indian Institute of Technology Roorkee, Roorkee – 247 667, INDIA, (e-mail: vinodfee@iitr.ernet.in).

K. K. Deepak is with the Department of Physiology, All India Institute of Medical Sciences, New Delhi - 110 029 (e-mail: kkdeepak@gmail.com).

palpitation. The subjects were also instructed not to use any medicine 24 hours before recording; no consumption of tea or foodstuff, coffee or any other caffeinated beverages at least two hours before the testing. Then the subjects were given 10-15 minutes of rest in sitting posture.

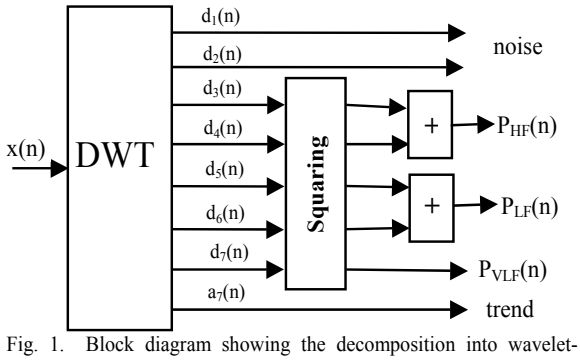

Fig. 1. Block diagram showing the decomposition into wavelet-filtered components and calculation of instantaneous power.

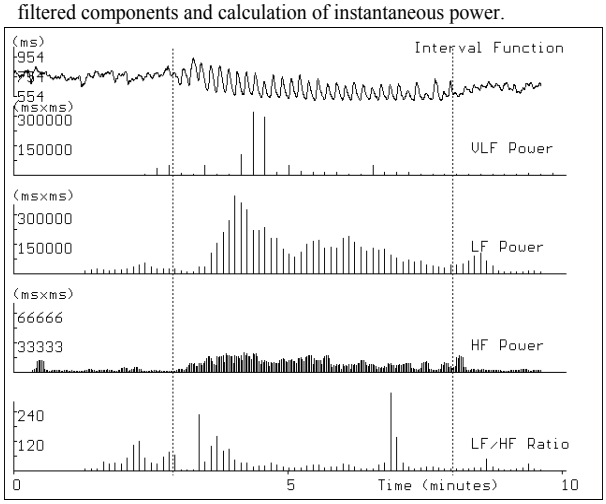

Fig. 2. Estimated dynamics of Interval Function, VLF, LF and HF band powers and LF/HF ratio of RR variability signal from a healthy subject (M/36) during deep breathing test in sitting posture using Debauchies-3 wavelet.

The ECG data of standard Lead II were obtained from the selected subjects at All India Institute of Medical Sciences, New Delhi using NI® data acquisition card PCI-6024E under a standardized condition in a quiet room, at comfortable light and temperature levels, with the subjects in sitting posture. The analysis is performed on a series of uninterrupted, unfiltered fixed data duration of 10-minutes. The ECG was A/D converted at 500 Hz sampling frequency, 12-bit resolution, and then stored and processed on a PIV processor based machine. The recognition of the QRS complexes in the ECG and the detection of R-wave were performed by means of wavelets [7]. No interpolation of original signal was implied and short-term recording free of ectopy, missing data and noise were used to ensure the sinus node beats. The derived RR interval time series was evaluated for quality assessment through visual inspection and editing. RR interval series was transformed into evenly sampled signals by two-step procedure to avoid spectral distortions. Firstly, Berger's algorithm was applied to obtain a smooth continuous line, which in second step, was resampled evenly at 4.8 Hz [8].

B. Procedure of Autonomic Function Testing

After the rest ECG was recorded for 5 minute pretest + test + post test 5 minutes for the analysis of cardiovascular responses using a noninvasive standard battery of four tests. All the tests were started and ended on verbal commands.

1) Deep Breathing Test (DBT): The subjects were given continuous signal to breathe (inhale and exhale) deeply and slowly at the rate of 6 breaths per minute for 5 minutes.

2) Valsalva Maneuver (VM): The subjects were asked to raise the intrathoracic pressure to 40 mm of Hg through a mouthpiece connected to a mercury manometer and maintain the pressure for 15 seconds. No deep breathing was allowed after the VM. After the release of intrathoracic pressure, the mouthpiece was removed and the subjects were instructed to sit quietly.

3) Handgrip Test (HGT): The Maximum voluntary contraction (MVC) was determined by asking the subjects to press the handgrip dynamometer with dominant hand with maximum possible force for about 3 seconds. Then the process was repeated twice. The highest among the three readings was considered as MVC. The subjects continuously pressed the dynamometer at 30% of their MVC for 4 minutes using their dominant hand.

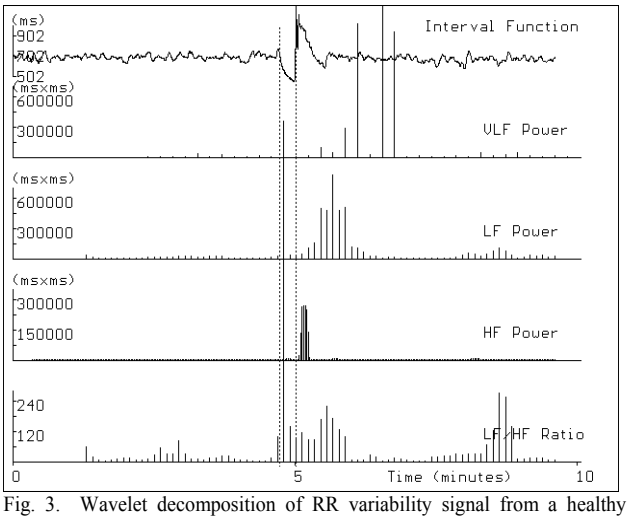

Fig. 3. Wavelet decomposition of RR variability signal from a healthy subject (M/36) during Valsalva Maneuver in sitting posture Debauchies-3 wavelet. The left dotted line marks the onset of the test and the right one indicates the start of posttest period.

4) Cold Pressor Test (CPT): The subjects were asked to immerse their hand up to the wrist in 10º C cold water for one minute during the test. After the test, the hand was taken out and covered with a towel.

TABLE I
HRV PARAMETERS OBSERVED UNDER AUTONOMIC FUNCTION TESTS

	DBT	VM	HGT	CPT
mean	657.3	677.1	650.2	739.4
SD	93.1	56.4	44.5	36.6
$\mathbf{P_{HF}}$ $(ms)^2$	6698	5389	2469	1591
$\mathbf{P_{LF}}$ $(ms)^2$	88538	61117	31586	21190
$\mathbf{P_{VLF}}$ $(ms)^2$	30897	152537	27879	20160
$\mathbf{P_{tot}}$ $(ms)^2$	126133	219043	61934	42941
$\mathbf{P_{LFn}}$ (%)	92.9	91.8	92.7	93.0
$\mathbf{P_{HFn}}$ (%)	7.0	8.1	7.2	6.9
$\mathbf{P_{LF}}$/ $\mathbf{P_{HF}}$	13.2	11.34	12.7	13.3

SD = Standard deviation, P_{VLF} = Mean power of the very low-frequency component (0.01875-0.0375 Hz), P_{LF} = Mean power of the low-frequency component (0.0375-0.15 Hz), P_{HF} = Mean power of the high-frequency component (0.15-0.6 Hz), $P_{tot} = P_{VLF} + P_{LF} + P_{HF}$, $P_{LFn} = P_{LF}/(P_{tot} - P_{VLF})$, Normalized LF band power; $P_{HFn} = P_{HF}/(P_{tot} - P_{VLF})$ Normalized HF power; P_{LF}/P_{HF} = The ratio between the power of LF and HF component

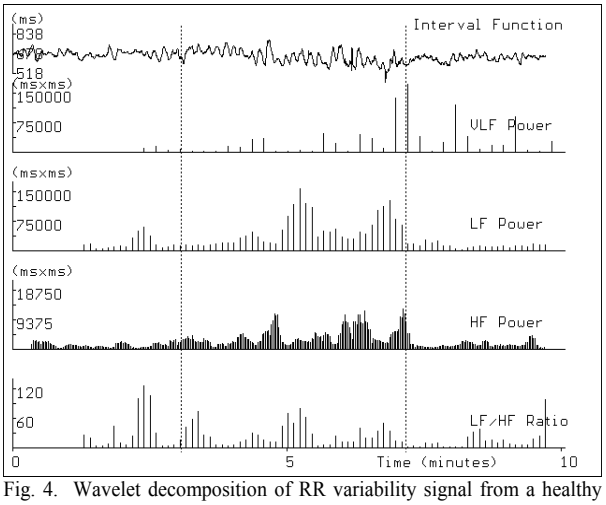

Fig. 4. Wavelet decomposition of RR variability signal from a healthy subject (M/36) during handgrip test in sitting posture Debauchies-3 wavelet.

C. Signal Processing

For the purpose of wavelet analysis, the dyadic decomposition has forced to choose a sampling frequency of 4.8 Hz and to take decomposition level, J = 7 in order to have the best possible correspondence between physiological subbands and resulting dyadic frequency bands [9]. The resulting bands are VLF = 0.01875 - 0.0375 Hz, LF = 0.0375 - 0.15 Hz, and HF = 0.015 - 0.60 Hz. The discrete wavelet transform algorithm is implemented using the Daubechies wavelet (DW-3) as shown in Fig. 1. The desirable requirements of successful application of wavelet analysis to HRV signals that events are well localized in time and exhibit morphologic and spectral variations within these localized events have been achieved. Objectively viewing the signal at different scales should provide meaningful new information.

III. RESULTS AND DISCUSSION

The most conspicuous periodic component of HRV is the respiratory sinus arrhythmia (RSA), which is considered to range from 0.15 to 0.4 Hz. In addition to the physiological influence of breathing on HRV, this high frequency (HF) component is generally believed to be of parasympathetic origin. Another widely studied component of HRV is the low frequency (LF) component ranging form 0.04 to 0.15 Hz. The rhythms within the LF band are nowadays generally thought of being both of sympathetic and parasympathetic origin [10]. Thus, HRV is commonly examined through spectral analysis and, e.g., the LF/HF ratio is considered as an index of sympathovagal balance.

Due to the complex control systems of HRV, it is presumable that the characteristics of HRV (e.g. the powers and frequencies of LF and HF components) vary in time. Especially, changes in physiological conditions may produce significant such variations. In order to analyze such changes, time-frequency methods are required. For example, the obtained RR interval function for a selected subject is presented on top of Fig. 2. The start and end of test time instant of deep breathing test are indicated by dotted lines. The changes between the HF and LF variability due to test are evident. The LF and HF band powers and the LF/HF ratio as a function of time were calculated using the scheme shown in Fig. 1 [5, 9]. The parasympathetic reactivity due to DBT is evident in HF band and followed by sympathetic activation. Further the band powers returns to their pretest range after the test.

Fig. 3 shows the decrease in RR intervals during VM and sudden increase following the test. Here LF and VLF band powers follow the changes in HF band. However the LF/HF ratio shows sympathovagal activation without any delay and

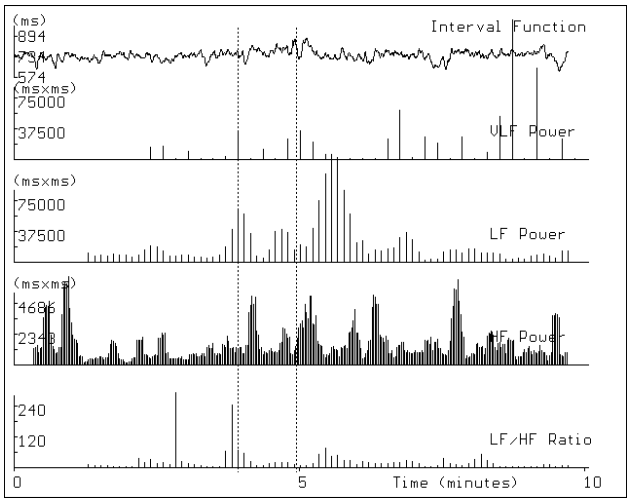

Fig. 5. Estimated dynamics of Interval Function, VLF, LF and HF band powers and LF/HF ratio of RR variability signal from a healthy subject (M/36) during cold pressor test in sitting posture using Debauchies-3

settled to steady state following the settling of HF power. Which again confirms the parasympathetic reactivity.

The overall band powers are considerably less during the HGT and CPT as shown in Fig. 4 and Fig. 5. Also HF band power elevations are not prominent as in case of DBT and VM, but the LF power changes are quite evident during the test for HGT and even after test for CPT.

To analyze time-variant changes in the modulation within each subband, we calculated the instantaneous power for the reconstructed detail signals as the sum of squares of the coefficients as shown in spectral decomposition (Figs. 2-5). Because of large sample-to-sample variation, the power of each wavelet-filtered component was smoothed using a moving average (MA) filter as shown in Fig 2. To track time-varying changes, relatively short filters lengths were used. Table I provide the various averaged quantification measures for a single subject under the DBT, VM, HGT and CPT. A look at the Table I conveys that the VLF power is highest for VM and least for CPT which may be due to vasculature activities involved. For LF and HF band powers, the trend is in descending order of DBT, VM, HGT and CPT. But the nature of the test in terms of sympathetic or parasympathetic activity is self explanatory by the absolute values of LF and HF band powers which is more than double for DBT and VM as compared to HGT and CPT. On the other hand the normalized values are in the same range for all the test, which conveys averaging effect over the analysis interval. The LF/HF power ratio also remains relatively stable (11.3 to 13.3) for all the tests conducted and thus averaged values like those given by FT hardly convey any information about the induced regular changes in beat-to-beat intervals. Thus, this ratio fails to represent sympathovagal balance under the designed protocol.

IV. Conclusion

This study shows the effect of different autonomic function tests and highlights the sequence of cardiovascular dynamics. The has also been able to demonstrate that HRV analysis based on averaged parameters as in nonparametric methods has some serious limitations due to nonstationary nature of HRV signal. Here this analysis has been able to establish that averaged values are unable to demonstrate the difference between sympathetic activity tests (DBT, VM) and parasymapathetic reactivity tests such as HGT and CPT. Researchers quantifying cardiovascular variability need to be aware of the effect of the protocol used and need to document their protocol fully. In addition, dynamics of time-frequency analysis must also taken into account for better interpretation of results.

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