International Journal of Research Studies in Biosciences (IJRSB)
Volume 3, Issue 5, May 2015, PP 99-106
ISSN 2349-0357 (Print) & ISSN 2349-0365 (Online)
www.arcjournals.org

Influence of Age and Gender on Heart Rate Variability: An Analysis Using Different Non-Linear Techniques

Subhojit Sarker

Department of ECE
Siliguri Institute of Technology
West Bengal, India
subhojitsarker@gmail.com

Ankur Ganguly

Batanagar Institute of Engineering
Management and Science
West Bengal, India
anksjc2002@yahoo.com

D.N. Tibarewala

School of Bioscience and Engineering,
Jadavpur University
West Bengal, India
biomed.ju@gmail.com

Abstract: *Heart Rate Variability Analysis involves one of the emerging tools to study the autonomic activity of the human heart. Recent researches on HRV have suggested that besides traditional linear analysis techniques, the non-linear parameters can also provide valuable information for the physiological interpretation of heart rate fluctuations. This paper presents a comprehensive characterization of HRV using various non-linear parameters based on age and gender in order to establish physiological correlates. The study population comprises of 321 male and female subjects from various tea-gardens located in the North Eastern regions of West Bengal. Suunto T6 Heart Rate Monitor was used for the acquisition of RR interval series and the analysis of the data was carried out using Kubios HRV 2.0 and PSPP software. The statistical analysis was performed to bring out a comparison between the male and female population, using paired t-test and Pearson's correlation. Irrespective of the gender, subjects in the >40 years category were associated with lower variability in the HRV signal, i.e. decrease in FD, CD, ApEn, SanEn, SD1/SD2, PLS and an increase in REC, DET and L_{max}. The present study establishes that increasing age is associated with poorer cardiovascular health and outcomes for the population under study.*

Keywords: *RRI, HRV, ANS, PPA, RPA, NLP*

1. INTRODUCTION

The variation in beat-to-beat intervals of the heart rate is called Heart Rate Variability (HRV) [1]. It is a measure of the continuous interplay between two branches of autonomic nervous system (ANS), the sympathetic and parasympathetic influences on heart rate that yields information about autonomic flexibility [2].

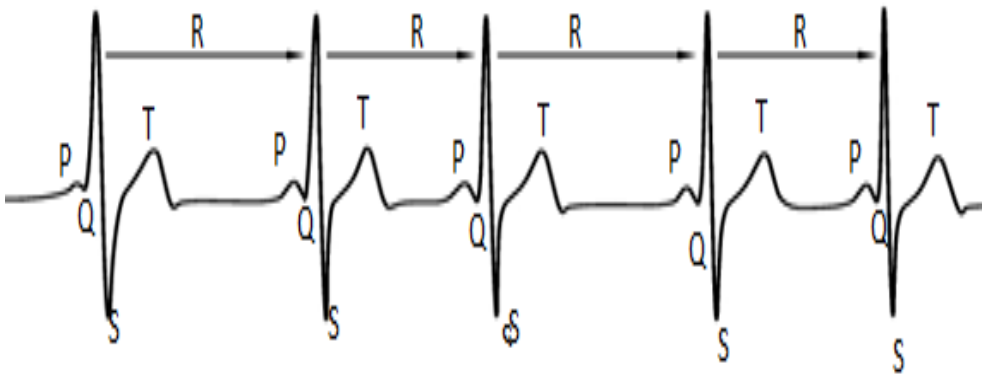

Fig1. *Heart Rate Variability is measured by calculating the duration between R peaks*

Analysis of HRV have been used to quantify risk in a wide variety of both cardiac and non-cardiac disorders such as stroke, multiple sclerosis, end stage renal disease, neonatal distress, diabetes mellitus, myocardial infarction, valvular heart disease and congestive heart failure [3-8]. To evaluate the HRV, the linear methods analyzed in both the time-domain and frequency domain; as well as the Non-Linear (NL) methods can be used. However, recently the non-linear methods are being emphasized more as they address the complex fluctuations of rhythm [9]. The different non-linear parameters (NLPs) considered in this paper are:

I. Poincare Plot Analysis (PPA)

- SD1(ms) - Standard deviation of the points perpendicular to the line-of-identity
- SD2 (ms)- Standard deviation along the line-of-identity
- SD1/SD2 – Ratio of SD1 to SD2
- S – Area of the ellipse
- SDRR – Standard Deviation of RR intervals

II. Recurrence Plot Analysis (RPA)

- L_{mean} – Mean line length (beats)
- L_{max} – Max line length (beats)
- REC - Recurrence rate (%)
- DET – Determinism (%)
- ShanEn - Shannon Entropy

III. Detrended Fluctuation Analysis (DFA)

- Slope $\alpha 1$ – Short-term fluctuations
- Slope $\alpha 2$ - Long-term fluctuations

IV. Power Law Slope (PLS)

V. Fractal dimension (FD)

VI. Correlation dimension (D2)

VII. Approximate entropy (ApEn)

VIII. Sample entropy (SampEn)

2. MATERIALS AND METHODS

In this research a total of three hundred twenty one subjects were chosen on stratified random selection basis from various tea-gardens located in the North Eastern regions of West Bengal. The sample collection was carried out for 213 male subjects and 108 female subjects.

2.1. Data Acquisition

The purpose and procedure associated with data-collection was first explained in detail in order to collect the samples. After taking the consent of the subjects, the entire process of data collection was done in two steps:

- Questionnaire form was filled. The different parameters considered in the questionnaire schedule were validated by consulting one registered medical practitioner associated with the Jadavpur University, Kolkata.
- RRI series were obtained using Suunto T6 Heart Rate Monitor. Suunto t6 heart rate monitor is a device that evaluates the time between the heartbeats and provides accuracy in the range of milliseconds and also records the inter-beat intervals for further analysis. The device package shown in Fig.2 consists of Suunto t6, Transmitter belt, Suunto Training Manager Software and PC-interface cable. The Suunto Training Manager PC software makes use of the heart rate variation information to analyze and compute several other body parameters.

Fig2. *Suunto T6 Heart Rate Monitor*

2.2. Data Analysis

In this study, SuuntoT6 Heart Rate Monitor was used to record the HRV signal for each of the subjects. The recording was measured for 5 minutes duration to obtain the short-term HRV data. In order to ensure stability and acquaintance of the subjects with the recording equipment and environment, the readings were taken in three time intervals of 5 minutes, 10 minutes and 15 minutes. For analysis, the data recorded in the third interval i.e. the 15^{th} minute recording was chosen as it showed the highest stability. Once the data was acquired, it was shifted to a personal computer using an USB data cable. To acquire the RR intervals from the HR monitor, the Suunto Training Manager 1.3.3 software was used for the data collection. The SuuntoT6 Heart Rate Monitor has the options of recording several parameters, viz. HR, EPOCH, Respiration Rate, VE, VO2, Energy, Speed, R-R Interval. Out of these, the data of R-R intervals were accepted. Once the RR interval series were available and stored as .txt files, it was then applied as input to Kubios HRV 2.0 software for evaluation and analysis. The statistical analysis was performed using PSPP software to bring out a comparison between the male and female population, using paired t-test and Pearson's correlation.

3. RESULTS AND DISCUSSION

3.1. Population Analysis

In the study population, the male subjects were in the age group of 16 to 76 years whereas the female subjects were in the age group of 17 to 86 years. Out of the 108 females, 84 were married, 21 were unmarried and 3 were in the widow/divorcee category. In case of males, 136 were married and the remaining was unmarried. Majority of the tea-garden population was found to be below the poverty line and were resident habitats for $\leq$3 generations. 37.96% of the females and 78.4% of the male population were smokers. Also, 25% (female) and 64.78% (male) were reported to consume alcohol. Majority of both the sexes were engaged in physical exercise and more than 95% were found to be non-vegetarians. The sleep duration of the females were seen to be more than the males. But, more than 80% of both the genders worked for >7 hours and were mainly engaged in manual work. On an average, 20% of the population had history of cardiac disease in family. A large number of subjects, 63.89% (female) and 68.08% (male) were found to suffer from disease recently. However, only 13.62% of the males and 25% of the females were under regular medication. Of the female population, 28.7% had undergone menopause and 79.63% was in the post pregnancy category.

3.2. Non-Linear Analysis of HRV

The RR intervals obtained were used to compute the various non-linear indices of HRV. Different non-linear parameters as discussed were selected which describe the scaling, complexity and chaotic characteristics of the HRV signal. The Non-Linear parameters as shown in Table 1 to Table 3 represent the parameter summary of the male and female subjects from the study population based on different age groups and are expressed in (mean±s.d.) format.

Table1. *Characterization of Male and Female Population (<20 years age group)*

PARAMETER		Age Group < 20 years		P value	Correlation
		FEMALE	MALE		
Poincare Plot Analysis	SD1	18.836±4.9824	24.175±6.5671	0.102	-0.114
	SD2	68.6818±29.9504	86.1917±25.5161	0.092	0.149
	SD1/SD2	0.3102±0.1241	0.3136±0.1469	0.658	0.314
	S	4109.8245±2167.0635	6447.7938±2223.8371	0.073	-0.579
	SDRR	50.65384±20.667	63.68996±17.142	0.083	0.080
Recurrence Plot Analysis	Lmean	23.7973±15.4957	17.7017±11.626	0.119	0.297
	Lmax	325.5455±121.863	266.2917±148.286	0.219	0.413
	REC	46.5336±16.5679	41.9242±13.815	0.160	0.211
	DET	99.07±1.1333	98.776±1.1127	0.575	0.100
	ShanEn	3.6758±0.5724	3.484±0.4993	0.133	0.513
Other Non-Linear Parameters	ApEn	0.9045±0.388	1.0266±0.2317	0.450	0.209
	SanEn	1.0207±0.5895	1.2063±0.4342	0.473	0.317
	DFA-α1	1.3391±0.3695	1.2751±0.2687	0.762	0.205
	DFA-α2	1.1001±0.2795	0.9465±0.1608	0.125	0.261
	CD(D2)	1.7348±1.2221	2.734±1.213	0.060	-0.331
	FD_HIGUCHI	1.5105±0.6399	1.5915±1.0875	0.754	0.038
	PLS	-1.064	-1.1		

Table2. *Characterization of Male and Female Population (21-40 years age group)*

PARAMETER		Age Group 21-40 years		P value	Correlation
		FEMALE	MALE		
Poincare Plot Analysis	SD1	17.853±6.8518	19.679±9.2095	0.424	0.499
	SD2	59.8685±30.7628	67.4±35.5679	0.531	0.223
	SD1/SD2	0.3345±0.1583	0.3067±0.1236	0.684	-0.069
	S	3478.8822±2058.4795	4474.3334±3099.3127	0.444	0.642
	SDRR	44.52651±21.5487	49.97237±25.3281	0.588	0.308
Recurrence Plot Analysis	Lmean	16.1388±9.57596	14.1318±7.32913	0.070	-0.532
	Lmax	298.9726±132.1102	278.3254±134.254	0.350	-0.033
	REC	39.5159±11.5043	38.0393±10.074	0.235	-0.631
	DET	98.619±1.1459	98.659±1.1581	0.412	-0.445
	ShanEn	3.4454±0.4033	3.3541±0.3842	0.151	-0.546
Other Non-Linear Parameters	ApEn	1.0563±0.238	1.0639±0.1946	0.138	-0.340
	SanEn	1.2945±0.4095	1.2812±0.3826	0.247	-0.376
	DFA-α1	1.2223±0.3234	1.2942±0.2643	0.963	-0.247
	DFA-α2	1.0197±0.211	0.9454±0.1998	0.069	0.030
	CD(D2)	1.7708±1.2156	2.319±1.3021	0.233	0.048
	FD_HIGUCHI	1.2381±0.9428	1.3092±0.7551	0.035	0.488
	PLS	-1.198	-1.271		

Table3. *Characterization of Male and Female Population (> 40 years age group)*

PARAMETER		Age Group > 40 years		P value	Correlation
		FEMALE	MALE		
Poincare Plot Analysis	SD1	12.788±5.7341	13.756±7.4455	0.018	0.083
	SD2	51.9208±25.1132	51.7508±26.1426	0.370	0.073
	SD1/SD2	0.2602±0.09	0.2777±0.1279	0.120	-0.067
	S	2373.6553±1912.3092	2644±2244.6055	0.083	0.134
	SDRR	37.9253±17.9490	38.0469±18.8353	0.289	0.091
Recurrence Plot Analysis	Lmean	21.5433±19.0705	17.6217±7.144	0.209	-0.158
	Lmax	348.5417±87.222	328.5397±113.753	0.020	0.498
	REC	45.6246±11.1273	43.2963±8.4178	0.305	-0.251
	DET	99.24±0.8244	99.116±0.8363	0.177	-0.094
	ShanEn	3.6506±0.335	3.5891±0.3673	0.149	-0.179
Other Non-Linear Parameters	ApEn	1.0042±0.225	1.0358±0.1813	0.437	-0.286
	SanEn	1.1409±0.3634	1.2275±0.3542	0.206	-0.192
	DFA-α1	1.2225±0.1867	1.2868±0.2738	0.541	0.101
	DFA-α2	1.1237±0.1693	1.0758±0.1821	0.004	0.148
	CD(D2)	0.8732±0.78	1.2259±1.1333	0.009	-0.013
	FD_HIGUCHI	1.2895±0.7491	1.3841±1.1019	0.284	0.391
	PLS	-1.397	-1.594		

The graphical representations of the distribution of non-linear parameters for the female and male subjects depending on the selected age groups are shown in Figs. 3 to 5.

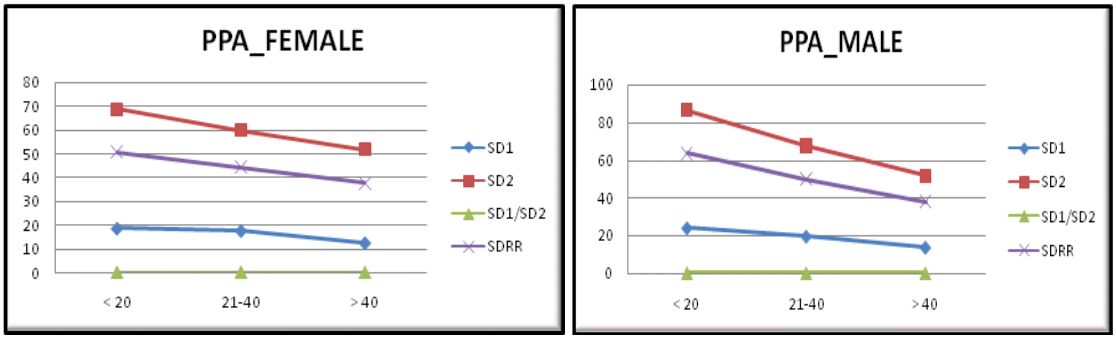

Fig3. *Poincare-plot Analysis of Females and Males for different age groups*

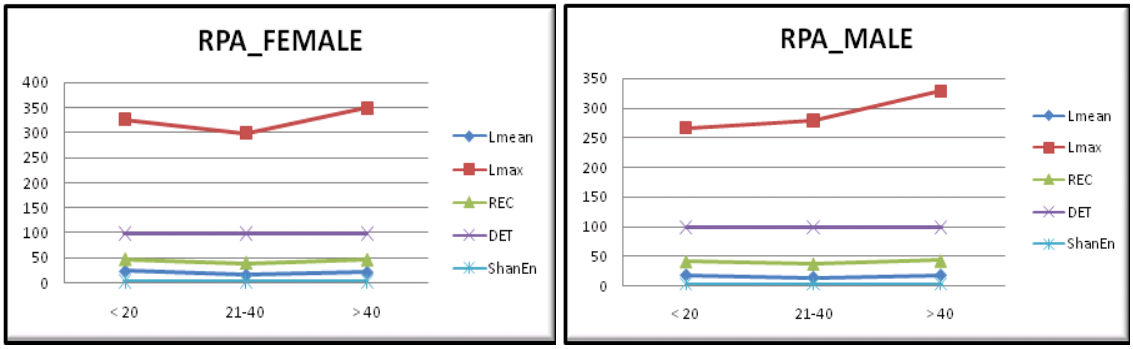

Fig4. *Recurrence-plot Analysis of Females and Males for different age groups*

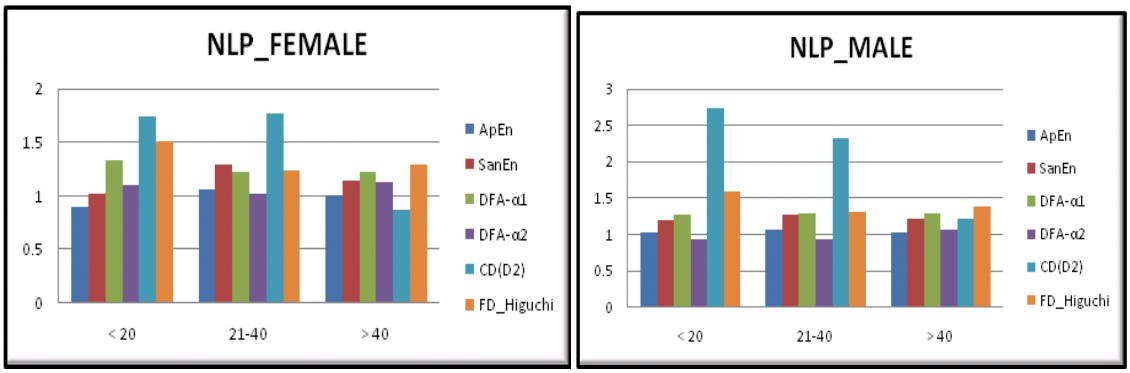

Fig5. *Distribution of various Non-Linear parameters of Females and Males for different age groups*

The various non-linear parameters for the female and male subjects have been represented in Table 1 to 3 and are based on different age groups. The physiological correlates derived from the obtained non-linear indices are as follows:

3.2.1. Female Population

From the obtained results of the Poincare Plot analysis, it can be seen that the value of SD1 and SD2 is maximum in the <20 age group, which indicate that subjects in this age group are healthier than the others. Also the ratio of SD1 to SD2 is seen to be maximum for the 21-40 age group, indicating more variation in the RR interval. The maximum area S of the Poincare plot pattern has been obtained for the <20 category and it is seen to be minimum for >40 category, suggesting low variability of the HRV signal in the later [10-12]. Considering the Recurrence quantification analysis (RQA), different quantitative parameters have been obtained from the recurrence plot [6, 10, 12, 13]. The %REC is seen to be smaller in the 21-40 years category, which indicates more variation in the RR intervals. DET is the percentage of recurrence points forming upward diagonal lines in the plot and is more in case of >40 years category. The maxline (Lmax) is higher in the 21-40 years category, indicating a large amount of "chaos". The ApEn has larger value for cardiac normal cases [12, 14-17], indicating higher variability in the beat to beat as obtained in the 21-40years category. DFA reflects the amount

of the randomness in R-R interval time series with values ranging from 0.5 (random) to 1.5 (correlated) and normal values of just over 1.0 [6,14,17]. DFA α1 is high in the <20 years category which suggest a normal signal indicating the fractalness in the data. CD has higher values for normal HR signals and this value falls as the beat to beat variation falls, indicating different cardiac diseases [6,12,14,17,18]. A large value of CD was obtained for the females in the 21-40 years age group whereas the value was minimum for the >40years category. FD obtained using the Higuchi's algorithm [19] was smaller for the elderly subjects as compared to those of the young. Higher value of FD indicates greater physiological health of the subject [6, 12, 13]. The power law slope was steeper in the >40 years category, suggesting abnormal health conditions [20, 21].

3.2.2. Male Population

From the obtained results of the Poincare Plot analysis, it can be seen that the value of SD1 and SD2 is maximum in the <20 age group, which indicate that subjects in this age group are healthier than the others. Also the ratio of SD1 to SD2 is seen to be maximum for the <20 age group, indicating more variation in the RR interval. The maximum area S of the Poincare plot pattern and SDRR has been obtained for the <20 category and it is seen to be minimum for >40 category, suggesting low variability of the HRV signal in the later [10-12]. Considering the Recurrence quantification analysis (RQA), different quantitative parameters have been obtained from the recurrence plot [6, 10, 12, 13]. The %REC is seen to be more for the >40 years category and lower in the male population between 21-40 years. Similar studies have indicated that as the percentage of REC increases the health percentage of heart decreases due to less variation in RR intervals and vice versa. DET is more in case of >40 years category. Higher values of DET, show the changes in HRV that may indicate pathological conditions. The maxline (Lmax) is seen to be minimum in the <20 years category, indicating a large amount of "chaos". The ApEn and SanEn has larger value for cardiac normal cases [12, 14-17], indicating higher variability in the beat to beat as obtained in the 21-40years category. CD has higher values for normal HR signals and this value falls as the beat to beat variation falls, indicating different cardiac diseases [6, 12, 14, 17, 18]. A large value of CD was obtained for the males in the <20 years age group whereas the value was minimum for the >40years category. A decreased power law slope was seen in the >40 years category, indicating cardiac abnormalities [20, 21].

4. CONCLUSION

This paper has presented the effect of age and gender on the non-linear parameters of HRV amongst the tea-garden population in North Eastern regions of West Bengal. Unlike the mixed literature on ethnic and behavioral differences, the finding that heart rate variability and complexity decline with age is widely cited and virtually undisputed. An inverse association between linear HRV measures and age was already established [22-23]. The findings of this research are based on non-linear parameters of HRV and were found to be in complete agreement with the previous studies using different time and frequency domain parameters of HRV. Irrespective of the gender, subjects in the >40 years category were associated with lower variability in the HRV signal, i.e. decrease in FD, CD, ApEn, SanEn, SD1/SD2, PLS and an increase in REC, DET and Lmax. However, no significant statistical correlation was found between both the genders considering the non-linear parameters of HRV. These findings can be related to the general concept of decreasing autonomic modulation with advancing age and the non linear characterization developed can be successfully utilized to excavate and establish the dependence of cardiac autonomic control.

REFERENCES

[1] Miyawaki E, Salzman C. Autonomic nervous system tests in psychiatry: implications and potential uses of heart rate variability. Integr Psychiatry 1991; 7: 21-28.

[2] Juan S. Heart rate variability: a noninvasive electrocardiographic method to measure the autonomic nervous system. Swiss Med Wkly 2004; 134: 514–522.

[3] Vandeput S, Verheyden B, Aubert AE, Huffel S V. Nonlinear Heart Rate Variability in a Healthy Population: Influence of Age, Computers in Cardiology. 2008; 35:53−56.

[4] Acharya UR, Joseph KP, Kannathal N, Lim CM, Suri JS. Heart rate variability: a review. Med Bio Eng Comput. 2006; 44:1031–1051.

[5] Appelhans BM, Luecken LJ. Heart rate variability as an index of regulated emotional responding. Review of General Psychology. 2006; 10:229-240.

[6] Watkins LL, Grossman P, Krishnan R, Blumenthal JA. Anxiety reduces baroreflex cardiac control in older adults with major depression. Psychosom.Med. 1999; 334-340.

[7] Carney R, Saunders R, Freedland K, Stein P, Rich M, Jaffe A. Association of depression with reduced heart rate variability in coronary artery disease. Am. J. Cardiol. 1995; 76: 562-564.

[8] Dekker JM, Crow RS, Folsom AR, Hannan PJ, Liao D, Swenne CA, Schouten EG. Low heart rate variability in a 2-minute rhythm strip predicts risk of coronary heart disease and mortality from several causes: The ARIC Study. Circulation. 2000; 102: 1239-1244.

[9] Perakakis P. Fractal analysis of cardiac dynamics: The application of Detrended Fluctuation analysis on short-term heart rate variability. Unpublished doctoral thesis, Granada University; 2009.

[10] Kumar H, Kaur K, Kaur G. Heart Variability Analysis by using Non-Linear Techniques and their Comparison. International Journal of Computer Applications. 2013; 65:20.

[11] Chua KC, Chandran V, Acharya UR, Min LC. Computer-based analysis of cardiac state using entropies, recurrence plots and Poincare geometry. J Med Eng Technol. UK; 2006.

[12] Acharya UR, Kannathal N, Krishnan SM. Comprehensive analysis of cardiac health using heart rate signals. Physiol Meas J. 2004; 25: 1130–1151.

[13] Acharya UR, Kannathal N, Seng OW, Ping LY, Chua T. Heart rate analysis in normal subjects of various age groups. Biomed Online J, USA. 2004; 3:24.

[14] Task Force of The European Society of Cardiology and The North American Society of Pacing and Electrophysiology, Heart rate variability Standards of measurement, physiological interpretation, and clinical use. European Heart Journal. 1996; 17: 354–381.

[15] Madhavi R, Ananth AG. Analysis and Characterization of Heart Rate Variability (HRV) Data of Different Sets of Subjects Using Nonlinear Measure (Approximate Entropy). International Journal of Computer Theory and Engineering. 2010; 2: 4:1793-8201.

[16] Richman JS, Randall MJ. Physiological time-series analysis using approximate entropy and sample entropy. Am J Physiol Heart Circ Physiol. 2000; 278:H2039–H2049.

[17] Sunkaria RK. Recent Trends in Nonlinear Methods of HRV Analysis: A Review. World Academy of Science, Engineering and Technology. 2011; 75: 566-571.

[18] Bogaert C, Beckers F, Ramaekers D, Aubert AE. Analysis of heart rate variability with correlation dimension method in a normal population and in heart transplant patients. Autonomic Neuroscience: Basic & Clinical. 2001; 90:142–147.

[19] Higuchi T. Aproach to an irregular time series on the basis of the fractal theory. Physica D. 1988; 31:277–283.

[20] Bigger JT, Steinman RC, Rolnitzky LM, Fleiss JL, Albrecht P, Cohen RJ. Power law behavior of RR-interval variability in healthy middle aged persons, patients with recent acute myocardial infarction, and patients with heart transplants. Circulation. 1996; 93:12:2142–2151.

[21] Vandeput S, Heart Rate Variability: Linear and Nonlinear analysis with applications in human physiology. PhD thesis; 2010.

[22] Kuo TB, Lin T, Yang CC, Li CL, Chen CF. Effect of aging on gender differences in neural control of heart rate. Am J Physiol Heart Circ Physiol. 1999; 277:2233–2239.

[23] Umetani K, Singer DH, McCraty R, Atkinson M. Twenty four hour time domain heart rate variability and heart rate: relations to age and gender over nine decades. J Am Coll Cardiol. 1998; 1:593–601.

AUTHORS' BIOGRAPHY

Subhojit Sarker is pursuing his Ph.D. from School of Bioscience and Engineering, Jadavpur University, India under the supervision of Prof. Ankur Ganguly and Prof. D.N. Tibarewala. He joined the Department of Electronics and Communication Engineering at Siliguri Institute of Technology, Siliguri, W.B., India in 2003 and is presently working as an Assistant Professor. He is author or co-author of more than 25 scientific papers in international/national journals and proceedings of the conferences. His areas of work include Bio-medical Signal Processing, Digital Image Processing and Neural networks.

Ankur Ganguly received his B.E. degree in Electrical & Electronics Engineering from Mangalore University, Karnataka, India, in 2000, the M.Tech. degree in Biomedical Engineering from MAHE, Manipal, Karnataka, India, in 2002, and the Ph.D. degree in Engineering from Jadavpur University, Kolkata, India, in 2011. He is presently Professor and Principal, Batanagar Institute of Engineering, Management and Science, Maheshtala, Kolkata. His research interests include biomedical signal processing, chaos theory, heart rate variability. At present, he is engaged in Non Linear applications and chaos theory in HRV and electrical machines.

D.N. Tibarewala was born in Kolkata, December 1951. He is presently a Professor of Biomedical Engineering and formerly was Director in the School of Bioscience & Engineering at Jadavpur University, Kolkata, India, he did his BSc (Honours) in 1971, and B. Tech (Applied Physics) in 1974 from the Calcutta University, India. He was admitted to the Ph.D. (Tech) degree of the same University in 1980. Having professional, academic and research experience of more than 30 years, Dr. Tibarewala has contributed about 100 research papers in the areas of Rehabilitation Technology, Biomedical Instrumentation and, related branches of Biomedical Engineering.