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Use of Non-linear Techniques to Investigate the Effect of Smoking and Alcohol Consumption on Heart Rate Variability

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Abstract

Background: Recent researches on Heart Rate Variability (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. Normally, smokers and alcoholics have increased sympathetic and reduced vagal activity as measured by HRV analysis. **Aim:** The paper aims to describe the significance of non-linear parameters of heart rate variability in order to investigate the consequence of smoking and alcohol consumption on cardio-autonomic control in both the genders. **Materials and Methods:** Current research is based on data acquired from three hundred healthy male and female subjects chosen on stratified random selection basis from various tea-gardens located in the North Eastern regions of West Bengal. The short-term R-R interval series were obtained using Suunto T6 Heart Rate Monitor and was then applied as input to Kubios HRV 2.0 software for evaluation and analysis. The statistical analysis was performed using PSPP software to compute the paired t-test. **Results:** The results obtained indicate that males who smoke regularly have shown a significantly lower HR variability with decreased SD1/SD2, S, CD, FD and ApEn; as compared to the alcoholics. Also, the female subjects have shown negative association of alcohol consumption with majority of the computed non-linear indices of HRV. **Conclusion:** This study establishes that the Non-Linear parameters of HRV can also be successfully utilized to demonstrate reduced beat-to-beat variations in case of smoking and alcoholic population, thereby anticipating higher mortality.

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

1. Introduction

Heart Rate Variability (HRV) is an established and one of the most promising quantitative markers of autonomic activity. Analysis of Heart Rate Variability (HRV) has become an important widely used method for assessing cardiac autonomic regulation. Recent researches show that smokers have increased sympathetic and reduced vagal activity as measured by HRV analysis. The cardiovascular mortality and smoking have a strong correlation. Reduced cardiac autonomic function is measured by HRV

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that is associated with cardiac vulnerability. Studies show that smokers have increased sympathetic and reduced vagal activity as measured by HRV analysis[1]. Smoking vitiates the cardiovascular function due to its effect on ANS control[2]. Studies show that time and frequency domain measures of HRV with tobacco smoke exposure was negatively associated with all measures of HRV. Altered cardiac autonomic function, measured by reduction in HRV, is related with acute revelation to environmental tobacco smoke (ETS) and may be considered as a component of the patho-physiological mechanisms linking environmental tobacco smoke exposure and higher cardiac vulnerability. Also, it was established that during a parasympathetic maneuver, the vagal modulation of the heart was less intense in heavy smokers. Reduced autonomic control of the heart may be linked with undesirableconsequence attributed to cigarette smoking. Recently Zeskind and Gingras[3] have demonstrated that cigarette exposed fetuses have reduced HRV and interrupted temporal organization of autonomic regulation.Also, in case of acute alcoholic subjects, ECG indices of vagal activity have been accounted to have considerablylower indices of cardiac vagal nerve activity as compared to normal volunteers[4]. Of late researches have observed reduction in HRV with the acute intake of alcohol, signifying sympathetic activation and/or parasympathetic withdrawal. Ryan et al[5] have demonstrated a strong positive connectionamong average day time and nighttime HR measured during 24 h ambulatory BP monitoring and usual alcohol intake. Malpas et al. have confirmed vagal neuropathy in men with chronic alcohol dependence in long term HRV analysis.

The Linear analysis of HRV is broadly used to study the autonomic control in several conditions[6]. However, recently, the Non-Linear Methods of HRV analysis are emphasized more to quantify risk in a wide variety of both cardiac and non-cardiac disorders, as they describe the complex fluctuations of the rhythm[7] and also provide valuable information for the physiological interpretation of heart rate fluctuations[8]. This study examined the variations in non-linear parameters of HRV in smokers and alcoholics in order to assess its effect on cardio-autonomic function.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 α1 – Short-term fluctuations
- Slope α2 - 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. Data Acquistion and Analysis

2.1 Data Acquistion

In this research a total of three hundred healthy 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 200 male subjects and 100 female subjects. The average age of the male subjects was (mean±s.d. = 33.92±13.14years), with max age of 76 and min age of 16 years. Average age of the female subjects was (mean±s.d. = 34.94±11.67years), with max age of 86 and a min age of 17 years. In the study population, 40% of the females and 80% of the male population were smokers. Also, 30% (female) and 65% (male) were reported to consume alcohol.

All datas were recorded in wake state of activity and as well as at rest schedule. A data collection form was prepared for recording and validation (Signature or LTI taken in almost all cases) of the collected data in three sections as:

i. General Survey ,
ii. Life Style survey, and
iii. Medical Survey

The 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 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.

2.2 Data Analysis

The recordings from the SuuntoT6 Heart Rate Monitor were 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 the paired t-test.

3. Results and Discussion

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 4 represent the parameter summary of the male and female subjects from the study population and are expressed in (mean±s.d.) format.

From the obtained results in Table 1 and 2, it can be seen that irrespective of the gender non-smokers have elevated values of Poincare plot parameters i.e. SD1, SD2, SD1/SD2, S and SDRR as compared to the smokers. Higher values of Poincare plot parameters incase of the non-smokers indicate more variation in the RR interval, which suggests that subjects in this category are healthier than those who smoke regularly[9–11].Considering the recurrence quantification analysis (RQA)[10,12],the %REC quantifies the percentage of plot occupied by recurrence points and it is seen to be more for both the male and female smokers. As the percentage of REC increases, the health percentage of heart decreases due to less variation in RR intervals and vice versa.DET is the percentage of recurrence points forming upward diagonal lines in the plot and is higher for males and females who smoke. Higher values of DET show the changes in HRV that may indicate pathological conditions.The maxline (Lmax) is the length of the longest line of recurrence plots in a continuous row within the plot and is seen to be minimum in case of smokers, indicating a large amount of "chaos".The value of ApEn and SanEn is seen to be lower in case of the male and female subjects who smoke and lower values of ApEn and SanEn is generally associated with cardiac abnormalities due to smaller variation in the RR series[13]. The DFA technique is a measurement which quantifies the presence or absence of fractal correlation properties[14]. Decreased DFA (also called α1) obtained incase of the smokers in both the sexes may be associated with adverse outcomes in cardiac patient populations.A Correlation dimension (CD) factor is defined to obtain a quantitative measure of the nature of trajectory of the phase space plot. It

Table 1. Characterization of Male Population (Smokers/Non-smokers)

PARAMETER		MALE SUBJECTS		P value
		SMOKERS	NON-SMOKERS	
N		160	40	
Poincare Plot Analysis	SD1	18.052±8.9675	19.8195±9.3505	0.5697
	SD2	64.488±35.2771	66.3434±26.3883	0.3802
	SD1/SD2	0.2969±0.1219	0.3061±0.1238	0.4807
	S	4019.2139±2824.5364	4650.5623±3561.557	0.8721
	SDRR	47.66494±25.13424	49.1736±19.2262	0.4011
Recurrence Plot Analysis	Lmean	16.2976±8.71696	12.9113±3.6374	0.007
	Lmax	289.6647±132.2159	299.652±131.581	0.4964
	REC	40.9322±10.875	36.7636±7.4052	0.0178
	DET	98.834±1.116	98.7084±0.9542	0.3446
	ShanEn	3.4716±0.4289	3.3171±0.28001	0.022
Other Non-Linear Parameters	ApEn	1.0397±0.2081	1.0939±0.13	0.0227
	SanEn	1.2438±0.3977	1.30413±0.306	0.0852
	DFA-α1	1.2892±0.262	1.29241±0.282	0.6234
	DFA-α2	0.9903±0.199	0.9618±0.198	0.2382
	CD(D2)	1.9508±1.376	2.3753±1.2244	0.3705
	FD_HIGUCHI	1.4262±0.975	1.134±0.566	0.0727
	PLS	-1.23	-1.226	

Table 2. Characterization of Female Population (Smokers/Non-smokers)

PARAMETER		FEMALE SUBJECTS		P value
		SMOKERS	NON-SMOKERS	
N		40	60	
Poincare Plot Analysis	SD1	15.263±5.308	17.785±7.394	0.3119
	SD2	54.3317±24.1119	61.856±32.381	0.78131
	SD1/SD2	0.3128±0.1306	0.317±0.153	0.83252
	S	2750.48±1680.02	3632.306±2248.318	0.26518
	SDRR	40.1400±16.8805	45.852±22.786	0.72711
Recurrence Plot Analysis	Lmean	19.2771±16.2771	17.411±10.733	0.55725
	Lmax	310.0488±127.7053	314.313±121.462	0.41394
	REC	41.7141±12.29	41.511±12.341	0.79386
	DET	98.801±1.1591	98.804±1.080	0.48578
	ShanEn	3.5419±0.4277	3.497±0.143	0.86779
Other Non-Linear Parameters	ApEn	0.9995±0.272	1.047±0.245	0.26629
	SanEn	1.2129±0.4631	1.244±0.407	0.73428
	DFA-α1	1.1958±0.3103	1.257±0.298	0.61034
	DFA-α2	1.0798±0.2175	1.033±0.210	0.68285
	CD(D2)	1.1797±0.9328	1.805±1.264	0.13607
	FD_HI-GUCHI	1.2797±0.7919	1.295±0.926	0.48086
	PLS	-1.103	-0.972	

has higher values for normal heart rate signals and this value falls as the beat to beat variation falls[15].The value of CD obtained was smaller for the male and female smokers in comparison to the non-smokers. Irrespective of the gender, FD obtained using the Higuchi's algorithm[16] was lower for the smokers, indicating cardiac abnormalities due to reduced or rhythmic variation of the RR series.Decreased PLS has been shown to be a marker for increased risk of mortality and the results obtained shows steeper slope incase of the smokers.

The Poincare Plot analysis obtained in Table 3 and 4, show that the ratio of SD1 to SD2 as well as area S of the Poincare plot pattern is lower in case of females who consume alcohol, which indicate less variation in the RR series. However, the mean value of the SD1/SD2 and S obtained for the male alcoholics is seen to be greater than the non-alcoholics, suggesting high variability of the HRV signal in the former[9-11].The values of Lmean, Lmax, REC, DET and ShanEn obtained from the recurrence quantification analysis (RQA) show elevated values incase of female alcoholics and lower values in case of male alcoholics. Similar studies have indicated that as the percentage of RQA parameters increases the health percentage of heart decreases and vice versa[12]. ApEn and SanEn is a measure to quantify the regularity or predictability of time-series data and show lower values for the cardiac abnormal signals, indicating smaller variability in the beat to beat[13]. In this study, the male subjects who consume alcohol have higher ApEn and SanEn

Table 3. Characterization of Male Population (Alcoholics/Non-alcoholics)

PARAMETER		MALE SUBJECTS		P value
		ALCOHOLICS	NON- ALCOHOLICS	
N		130	70	
	SD1	18.928±9.237	17.524±8.707	0.6832
	SD2	63.9043±35.5573	66.7±29.5119	0.6546
Poincare Plot Analysis	SD1/SD2	0.314±0.135	0.2711±0.108	0.1013
	S	4157.5474±3031.1332	4151.9070±2965.591	0.7175
	SDRR	47.45472±25.35327	48.97711±21.2478	0.7124
	Lmean	15.0956±7.87999	16.4324±8.2435	0.6235
	Lmax	278.413±127.5785	316.493±136.7704	0.1328
Recurrence Plot Analysis	REC	39.2455±10.5585	41.47893±9.8714	0.3440
	DET	98.685±1.181	99.0317±0.8331	0.1318
	ShanEn	3.4054±0.4062	3.49868±0.4009	0.3224
	ApEn	1.0605±0.1894	1.03456±0.2049	0.5015
	SanEn	1.2851±0.3796	1.20496±0.377	0.2947
	DFA-α1	1.2597±0.2706	1.34538±0.2509	0.2391
Other Non-Linear Parameters	DFA-α2	0.9821±0.201	0.9878±0.1964	0.9660
	CD(D2)	2.0783±1.3669	1.97645±1.335	0.9835
	FD_HIGUCHI	1.4624±1.0065	1.18058±0.6653	0.0202
	PLS	-1.203	-1.283	

Table 4. Characterization of Female Population (Alcoholics/Non-alcoholics)

PARAMETER		FEMALE SUBJECTS		P value
		ALCOHOLICS	NON- ALCOHOLICS	
N		30	70	
	SD1	15.004±5.7085	17.435±7.009	0.3013
	SD2	60.4778±25.5433	58.507±30.995	0.2990
Poincare Plot Analysis	SD1/SD2	0.269±0.105	0.3309±0.1533	0.0615
	S	3038.0894±1878.6607	3384.022±2156.723	0.9886
	SDRR	44.2430±18.0299	43.497±21.8041	0.3495
	Lmean	22.8441±19.2664	16.545±9.897	0.0293
	Lmax	349.5926±110.8413	300.395±125.402	0.1068
Recurrence Plot Analysis	REC	45.0515±12.8882	40.4337±11.908	0.0999
	DET	99.164±0.8762	98.682±1.152	0.1324
	ShanEn	3.664±0.4236	3.464±0.405	0.0679
	ApEn	0.9503±0.2833	1.055±0.241	0.0571
	SanEn	1.0971±0.465	1.277±0.407	0.0773
	DFA-α1	1.2157±0.2847	1.240±0.3104	0.8088
Other Non-Linear Parameters	DFA-α2	1.0983±0.2359	1.0352±0.2044	0.3073
	CD(D2)	1.3561±1.056	1.6381±1.2227	0.7887
	FD_HIGUCHI	1.3865±0.8956	1.7595±0.310	0.4930
	PLS	-1.076	-0.813	

than the females consuming alcohol.Irrespective of the gender, reduced DFA α1 obtained in case of the alcoholics indicate various types of cardiac abnormalities[14]. CD and FD have higher values for normal HR signals and these values decrease as the beat to beat variation falls[15,16]. The female alcoholics considered in this study have demonstrated lower values in comparison to the male alcoholics.

4. Conclusion

The present work has tried to carry out a population based research using different non-linear analysis methods in order to assess the non-linear parameters of HRV in smokers and alcoholics for both the male and female genders.Irrespective of the male or female population, subjects who smoke regularly have shown a significantly lower HR variability, with decreased SD1/SD2, S, CD, FD and ApEn. Numerous studies with various recording durations of ECG and different populations have showed a negative association of smoking with various measures of HRV[17–24], thereby predicting higher mortality. Findings regarding alcohol consumption and HRV are discordant. Some authors reported a positive connection in women[20,23], but others found a negative connection[17,18] or no connection[21,24]. The results obtained for female subjects belonging to the tea-garden population have shown negative association of alcohol consumption and HRV and thus are in accordance with the latter findings. Therefore this study establishes that the Non-Linear parameters of HRV can also be successfully utilized to demonstrate reduced beat-to-beat variations in case of smoking and alcoholic population, thereby anticipating higher mortality.

5. References

1. Behavioral Medicine.Institute of Australia. 2003. Available from http://www.behavioralmedicine.com/articls/hrv/001.htm.
2. Hayano J, Yamada M, Sakakibara Y, et al. Short, long term effects of cigarette smoking on heart rate variability. Am J Cardiol.1990; 65:84–8.
3. Zeskind PS, Gingras JL. Maternal cigarette-smoking during pregnancy disrupts rhythms in fetal heart rate. J Pediatr Psychol. 2006; 31(1):5–14.
4. Malpas SC, Whiteside EA, Maling TJ. Heart rate variability and cardiac autonomic function in men with chronic alcohol dependence.Br Heart J. 1991; 65:84–8.
5. Ryan JM, Howes LG. White coat effect of alcohol. Am J Hypertens.2000; 13:1135–8.
6. D'Addio G, Pinna GD, Maestri R, Acanfora D, Picone C, Furgi G, Rengo F.Correlation between Power-law Behavior and Poincar& Plots of Heart Rate Variability in Congestive Heart Failure Patients. Computers in Cardiology.1999; 26:611–4
7. Uzun S, Asyali MH, Celebi G, Pehlivan M. Nonlinear Analysis of Heart rate Variabilty. Conference Proceedings of the 23rd Annual International Conference of The IEEE Engineering In Medicine And Biology Society;2001 Oct 25-28; Istanbul, Turkey.
8. Task Force of the European Society of Crdiology and the North American Society of Pacing and Electrophisiology. Heart Rate Variability - Standard of Measurement, Phisiological Interpretation and Clinical Use. Circulation.1996; 93:1043–65.
9. 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.
10. 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.
11. Acharya UR, Kannathal N, Krishnan SM. Comprehensive analysis of cardiac health using heart rate signals. PhysiolMeas J. 2004; 25:1130–51.

12. Acharya UR, Kannathal N, Seng OW, Ping LY, Chua T. Heart rate analysis in normal subjects of various age groups. Biomed Online J. 2004; 3:24.
13. Richman JS, Randall MJ. Physiological time-series analysis using approximate entropy and sample entropy. Am J Physiol Heart Circ Physiol. 2000; 278:H2039–49.
14. Sunkaria RK. Recent Trends in Nonlinear Methods of HRV Analysis: A Review. World Academy of Science, Engineering and Technology.2011; 75:566–71.
15. Vandeput S. Heart Rate Variability: Linear and Nonlinear analysis with applications in human physiology[PhD thesis]. 2010.
16. Higuchi T. Approach to an irregular time series on the basis of the fractal theory. Physica D. 1988; 31:277–83.
17. Hemingway H, Shipley M, Brunner E, Britton A, Malik M, Marmot M. Does autonomic function link social position to coronary risk? The Whitehall II study. Circulation.2005; 111:3071-3077.
18. 18. Dietrich FD, Schindler C, Schwartz J, Barthelemy JC, Tschopp JM, Roche F, von Eckardstein A, Brandli O, Leuenberger P, Gold DR. Heart rate variability in an ageing population and its association with lifestyle and cardiovascular risk factors: results of the SAPALDIA study. Europace.2006; 8:521–9.
19. Dietrich FD, Schwartz J, Schindler C, Gaspoz JM, Barthelemy JC, Tschopp JM, Roche F, von Eckardstein A, Brandli O, Leuenberger P. Effects of passive smoking on heart rate variability, heart rate and blood pressure: an observational study. Int J Epidemiol. 2007; 36:834–40.
20. Kupari M, Virolainen J, Koskinen P, Tikkanen MJ. Short-term heart rate variability and factors modifying the risk of coronary artery disease in a population sample. Am J Cardiol.1993; 72:897–903.
21. Tsuji H, Venditti FJ Jr, Manders ES, Evans JC, Larson MG, Feldman CL, Levy D. Determinants of heart rate variability. J Am CollCardiol. 1996; 28:1539–46.
22. Ganguly A. Characterization of HRV among the population of Northern hilly region of West Bengal[Unpublished PhD thesis] Jadavpur University; 2011.
23. Janszky I, Ericson M, Blom M, Georgiades A, Magnusson JO, Alinagizadeh H, Ahnve S. Wine drinking is associated with increased heart rate variability in women with coronary heart disease. Heart.2005; 91:314–8.
24. Christensen JH, Skou HA, Fog L, Hansen V, Vesterlund T, Dyerberg J, Toft E, Schmidt EB. Marine n-3 fatty acids, wine intake, and heart rate variability in patients referred for coronary angiography. Circulation.2001; 103:651–7.