Study of the Aging Effects on HRV Measures in Healthy Subjects

Krishan Pal Singh Yadav and B. S. Saini

Abstract*—In this article, a study has been carried out to analyze the effect of aging, in healthy individuals, on heart rate variability (HRV) using time-domain, frequency-domain and Poincaré plot techniques. For this study data is taken from a standard database i.e. Fantasia Database which contains 20 elderly (68-85 years old) and 20 young (21-34 years old) strictly tested healthy individuals for comparability of result more extensive. The results convey that (i) The time domain methods provide a distinction in young and elderly groups in terms of mean coefficient of variance reduced by 47.03%, mean standard deviation of all RR intervals reduced by 45.37%, mean standard deviation of differences between adjacent RR intervals reduced by 54.81%, and mean root-mean-square value of successive differences between adjacent RR intervals reduced by 47.14% of young age group. (ii) In frequency domain analysis, Welch method shows that the peak frequencies VLF, LF and HF are not much affected by aging and power spectral density reduced significantly, particularly LF and HF reduced to one sixth that of young age group. The power ratio LF/HF is same for both age group which suggest that aging establishes a new equilibrium between two branches of autonomic nervous system. (iii) Auto Regressive (AR) method provides that peak frequencies VLF, HF are not much affected by aging but LF shifted to higher side and power values are reduced to one tenth of young age group.(iv)As compared to Welch method, AR provides higher power, lower LF/HF, smooth and high resolution peaks in all frequency bands of young and elderly age group but the disadvantages of the AR spectrum are the complexity of model order selection while Welch method allows simple and high processing speed algorithm. (v) From Poincaré Plot it is found that Poincaré cloud is spread over a wider area for young age group as compared to elderly and there is reduction of 20.9% in SD1, 45.35% in SD2, 41.37% in standard deviation of RR interval and 24.28% in ellipse area in elderly group as compared to young group. Thus with all measures HRV declines with aging.

***Index Terms*—Welch, HRV, poincaré plot, auto regressive**

I. INTRODUCTION

Heart rate variability (HRV) represents one of the most promising markers of a number of pathophysiological conditions. In 1981 S. Akselrod, D. Gordon, F. A. Ubel, D. C. Shannon, A. C. Barger and R. J. Cohen introduced power spectral analysis of heart rate fluctuations to quantitatively evaluate beat-to-beat cardiovascular control [1]. In 1986, G. Baselli, S. Cerutti, S. Civardi, D. Liberati, F. Lombardi, A. Malliani and M. Pagani [2] analyzed the parametric methods for HRV quantification. In 1995, G. Parati, J. P. Saul, M. Di Rienzo and G. Mancia [3] presented assessment of HR and BP spectra aimed at providing indexes of autonomic cardiovascular modulation. In 1997, M. A. Woo, D. K. Moser, L. W. Stevenson and W. G. Stevenson [4] established the superiority of Poincaré plots as a predictor of total mortality and risk of sudden death. In 1999, Jordi Altimiras gave a review on understanding autonomic sympathovagal balance from short-term heart rate variations [5]. In 2001, Federico Lombardi reviewed on HR variability analyses, not only for identifying patients at risk but also for describing changes in autonomic control mechanisms [6]. In 2001, M. Brennan, M. Palaniswami and P. Kamen [7] gave a detailed analysis of Poincaré plot geometry as applied to HRV and commented upon the linear parameters derived from it. Kallio et al. in 2002 [8] gave systematic comparison of time domain, frequency domain, nonlinear, geometrical and statistical analyses of HRV for revealing HRV differences between untreated patients with Parkinson's disease and healthy controls. In 2004, H. J. Burgess, P. D. Penev, R. Schneider and E. V. Cauter [9] evaluated cardiac autonomic control during sleep using spectral analysis and Poincaré plots. In 2006, Jong-Bae Choi examined the effect of age and ethnicity differences in short-term Heart-Rate Variability. Reference [10] shows that sympathetic activity increase and parasympathetic activity decreases with ageing. In 2006, D. Singh, K. VInod , S. C. Saxena and K. K. Deepak evaluated the aging effect on blood pressure and heart rate variations in healthy subjects. Time and frequency-domain analysis of HRV and BPV demonstrate that compared to young the elderly subjects have diminished HRV [11]. In 2011, K Umetani analysed the effect of age and gender effect on the normal range of time domain heart rate variability over nine decades in healthy subjects [12]. Thus with respect to age, HRV is known to decline with normal aging and decreased in HRV is considered to be an independent marker of a number of pathological conditions, including increased risk of mortality.

Manuscript received March 13, 2012; revised May 6, 2012.

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II. METHODOLOGICAL ASPECTS OF MEASUREMENT OF HRV

A. *Time Domain Parameters of HRV*

Time domain parameters involve computing indexes that are derived either directly from interbeat intervals, or from differences between adjacent interbeat intervals in the RR interval time series. Task Force of the European Society of Cardiology (ESC) and the North American Society of Pacing and Electrophysiology (NASPE) has recommended the following indices [13], [14].

1) SDNN (ms) – Standard deviation of all NN intervals.
2) RMSSD (ms) – The root mean square value of

successive differences between adjacent NN intervals.

3) SDSD (ms) – Standard deviation of differences between adjacent NN intervals.

4) CV (%)-Coefficient of variance. It is often called the relative standard deviation, since it takes into account the mean (average).

B. Spectral Analysis of HRV

For understanding how the overall variance is distributed in different frequency contributions, most of our knowledge on short HRV and autonomic cardiac modulation is based on two fundamental algorithms: the Welch and the Autoregressive method.

B.I FFT based Welch Periodogram

In this method, data segments are allowed to overlap by 50% or 70%, and each data segment will be weighted with a window function before calculating the periodogram as in (1). As a result, one has for the periodogram of each segment

$$\tilde{P}_x^p = \frac{1}{MU}\left|\sum_{t=1}^{M} x(t)w(t)\exp(-i\omega t)\right|^2 \quad (1)$$

The factor $U = M^{-1}\sum_{t=1}^{M} w(t)^2$ is a normalization factor for the power in the window function w(t). The Welch periodogram estimate as given in (2) will be then an average of these periodograms:

$$\hat{P}_x^w(\omega) = \frac{1}{L}\sum_{p=1}^{L}\tilde{P}_x^p(f) \quad (2)$$

B.II Autoregressive method

These methods use a different approach to spectral estimation, instead of trying to estimate the power spectral density directly from the data, they model the data as the output of a linear system driven by white noise and then attempt to estimate the parameters of that linear system as per (3) is

$$x(n) = -\sum_{k=1}^{p} a_k x(n-k) + \sum_{k=0}^{q} b_k w(n-k) \quad (3)$$

With this approach, the first step is to select an appropriate model for the process. In ARMA the data sequence is the output of a linear system characterized by a system function given in (4)

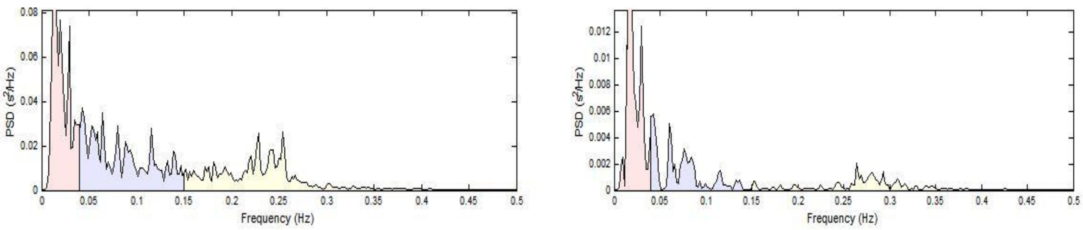
$$H(Z) = \frac{B(Z)}{A(Z)} = \frac{\sum_{k=1}^{q} a_k z^{-k}}{1+\sum_{k=1}^{p} b_k z^{-k}} \quad (4)$$

B.III Non-linear analysis using Poincaré plots

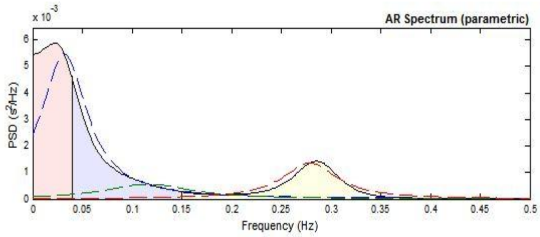
The most commonly used non-linear method of analyzing heart rate variability is the Poincaré plot [7]. The primary method for quantifying the Poincaré plot is known as the ellipse-fitting technique. In the medical literature these vectors are more commonly referred to as RR_n and RR_{n+1}, respectively. In the reference system of the new axis, the dispersion of the points around the X1-axis is measured by the standard deviation denoted by SD1. This quantity measures the width of the Poincaré cloud and therefore, indicates the level of short-term HRV. The length of the cloud along the line of identity measures the long-term HRV and is measured by SD2, which is the standard deviation around the X2-axis [7].

III. RESULTS AND DISCUSSION

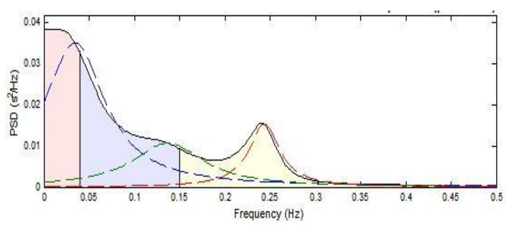
This section has undertaken to estimate the relation of HRV behavior to age. As shown in table I, RR interval for the young group is with an average span of 1044.77ms and RR interval for the elderly group is with an average span of 1013.07ms. The average of coefficient of variance (CV) for young and elderly groups is 7.06% and 3.72% respectively, indicating higher variability in younger subjects. The mean value of SDNN for young and elderly groups is 73.78 and 40.30 respectively, again indicating higher variability in younger subjects. Also mean SDSD and RMSSD reflect approximately 50% higher variability in young age group. The total average power for young group is 2297.12ms^2 and 391.50ms^2 for elder group which shows reduced variability in elderly group (Welch method) and similarly the total average power for young group is 3309.75ms^2 and 519.37ms^2 for elderly group which shows reduced variability in elderly group (AR method). The total average power for elderly group is reduced one sixth of young group. The mean LF/HF power ratio for young is 2.50 and 2.42 for elderly group (Welch method) and the mean LF/HF for young is 1.02 and 0.81 for elderly group (AR method) which remains same. Thus increasing of age there is no effect of aging on LF/HF power ratio for young and elderly group respectively. From table II it is found that as compared to Welch method, AR method provided higher power, lower LF/HF ratio in all frequency bands for young and elderly age group. The increased LF/HF ratio of Welch method suggests sympathetic activation with a well defined shift towards sympathetic dominance. From fig.1 AR method shows smooth and high resolution power spectrum than Welch method. The different power spectrum curves are as shown below



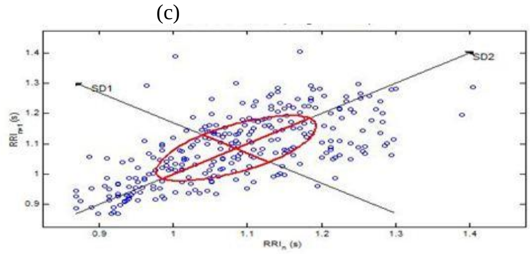
(a) (b)



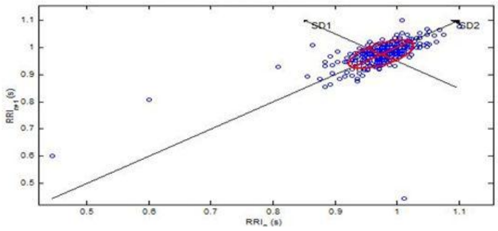
(c)



(d)



(e)



(f)

Fig. 1. (a)Power spectrum curve of young subject using Welch periodogram method; (b) Power spectrum curve of elderly subject using Welch periodogram method; (c) Power spectrum curve of young subject using AR method; (d) Power spectrum curve of elderly subject using AR method; (e) Poincare Plot for young subject; (f) Poincare Plot for elderly subject.

TABLE I: COMPARATIVE TABLE OF SELECTED HRV PARAMETERS FOR THE YOUNG AND ELDERLY AGE GROUPS.

Parameter	RR(ms) Mean	RR(min) mean	RR(max) mean	CV(%) Mean	SDNN(ms) mean	SDSD(ms) Mean	RMSSD(ms) Mean
Young group (mean)	1044.74	848.37	1240.50	7.02	73.78	59.65	49.82
Elderly group (mean)	1013.07	881.00	1117.75	3.72	40.30	26.95	26.33

TABLE II: COMPARATIVE TABLE OF FREQUENCY DOMAIN HRV PARAMETERS FOR THE YOUNG AND ELDERLY AGE GROUPS.

Parameter	VLF (Hz) mean	LF (Hz) Mean	HF (Hz) mean	P tot (ms2) mean	PVLF (ms2) mean	PLF (ms2) mean	PHF (ms2) mean	Ptot(nu) mean	PVLF(nu) mean	PLF(nu) mean	PHF(nu) mean	PLF/PHF mean
Young group (Welch method) mean	0.02	0.06	0.29	2297.12	703.12	883.5	710.5	146.88	46.68	59.61	40.38	2.50
Elderly group (Welch method) mean	0.03	0.05	0.27	391.50	175.37	134.75	81.37	204.20	104.20	63.37	36.62	2.42
Young group (AR method) mean	0.02	0.08	0.29	3309.75	950.75	1297.7	1060.6	132.91	50.11	43.52	39.26	1.02
Elderly group (AR method) Mean	0.02	0.30	0.27	519.37	341.12	88.37	88.63	359.83	348.56	33.18	46.71	0.81

TABLE III: POINCARÉ PLOT QUANTIFICATION MEASURES FOR YOUNG, HEALTHY SUBJECTS (68-85) FROM FANTASIA DATA BASE

Subjects	F2y01	F2y02	F2y03	F2y05	F2y06	F2y07	F2y08	F2y10	Mean
SDI	64.1	25.9	23.6	18.0	16.5	20.6	93.7	25.4	35.97
SD2	141.5	56.3	46.6	60.6	55.2	69.7	248.7	89.6	96.02
Ellipse Area (ms2)	28480.27	4578.65	3453.24	3425.11	2859.91	4508.47	73172.01	7146.13	15952.97
SDRR	109.85	43.82	36.94	44.70	40.74	51.40	187.95	65.86	72.65

TABLE IV: POINCARÉ PLOT QUANTIFICATION MEASURES FOR ELDERLY, HEALTHY SUBJECTS (68-85) FROM FANTASIA DATA BASE

Subjects	F2o01	F2o02	F2o03	F2o05	F2o06	F2o07	F2o08	F2o10	Mean
SDI	32.7	31.2	16.9	36.8	33.4	17.0	44.2	25.4	15.3

SD2	67.3	58.1	22.8	53.9	96.5	44.6	48.6	89.6	28.1
Ellipse Area (ms2)	6910.22	5691.94	1209.90	62228.25	10120.53	2380.74	6745.09	7146.13	1349.98
SDRR	52.91	46.6	20.07	46.15	72.21	33.75	187.95	46.45	22.62

From Poincaré plots we observed from Fig. 1(e) and Fig.1(f) that Poincaré cloud is spread over a wider area for young age group as compared to elderly. Table I and table II show the quantification measures for both age groups. Table III describes mean standard deviation along line of identity SD1 (35.97 ms), standard deviation perpendicular to line of identity, SD2 (96.02 ms), overall variability represented by ellipse area (15952.97 ms^2) and mean SDRR as the square root of the variance of the whole time series is 72.65ms for the young, healthy group. Again table IV standard deviation along line of identity, SD1 (28.43ms), standard deviation perpendicular to line of identity, SD2 (52.48 ms), overall variability represented by ellipse area (12079.58ms^2) and mean SDRR is 42.59 ms for the elderly group. There is reduction of 20.9% in SD1, 45.35% in SD2, 41.37% in SDRR and 24.28% in ellipse area in elderly group as compared to young group.

IV. Summary

In recent years, there is no doubt that the analysis of variability in heart rate has proven useful in understanding cardiovascular regulation in a range of conditions, including heart failure, diabetes, and hypertension. For this reason, the analysis of their variability has gained growing importance both for clinical evaluation and physiological studies. Following are the major conclusions on the basis of the work carried out in this paper: i) The time domain methods provide a distinction in young and elderly groups in terms of mean CV, mean SDNN, mean SDSD and mean RMSSD, all reduced approximately 50% of young age group ii) AR method shows higher power and high resolution spectrum than Welch method. The mean of central frequencies of VLF and HF bands do not seem to be affected by aging. iii) The mean LF/HF power ratio for young and elderly group (Welch method) and mean LF/HF for young and elderly group (AR method) which remains same. Thus increasing of age there is no effect of aging on LF/HF power ratio for young and elderly group respectively iv) From Poincaré Plot it is found that Poincaré cloud is spread over a wider area for young age group as compared to elderly which shows more power in young group. It is concluded that the age is an important factor to be considered for prognosis and diagnosis by HRV.

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