

Analysis of lagged Poincare plots in heart rate signals of women referred to meditation clinic

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Abstract— Poincare plots are commonly used to study non-linear behaviour of physiologic signals. Analysis of Poincare plots for various lags can provide interesting insights into the autonomic control of the heart. Furthermore, the width of Poincare plots can be considered as a criterion of short-term variability in heart rate signals. The hypothesis that Poincare plot indexes of heart rate variability (HRV) detect dynamic changes during meditation over the HRV in healthy women was examined. Poincare plots with six different lags (1-6) were constructed for two sets of data and the width of the Poincare plot for each lag was calculated. The results show that during meditation the width of Poincare plot tended to increase as the lag increased. During meditation, the width of Poincare plot with lag-1 was 2.5 ± 0.88 and with lag-6 was 4.77 ± 2.5 . The Poincare plot is a quantitative visual tool which can be applied to the analysis of R-R interval data gathered over relatively short time periods. The simplicity of the width of Poincare plot calculation and its' adaptation to the chaotic nature of the biological signals could be useful to evaluate heart rate signals during meditation.

Keywords— Heart Rate Variability, Lagged Poincare Plots, Meditation, Nonlinear Dynamics.

I. INTRODUCTION

The analysis of heart rate variability (HRV) provides valuable information to assess the autonomous nervous system (ANS). The HRV can be significantly affected by physiological state changes and many disease states. Hence, analysis of heart rate signals has encountered, for a long time, the favour of many researchers. Actually this interest is well deserved because of the great amount of information

embedded in the HR series; information were found directly linked to health [9] and cardiac diseases, like heart failure [8], angina pectoris [5], myocardial infarction [4]. Its low cost, non-invasive nature and effectiveness encourages the development of new HRV analysis methods to broaden and improve its applications.

The analysis of HRV is not an easy task due to its chaotic nature of time series. Traditional HRV analysis methods are based on linear methods in the time, frequency, or time-frequency domain. These methods have been extensively used to reveal fundamental control activity of sympathetic and parasympathetic activity of ANS.

Many researchers have stressed on the importance of nonlinear techniques to study HRV [10]. Nonlinear dynamical analysis of time series involves estimation of dynamical invariants from the reconstructed attractor, such as, dimensions, Lyapunov exponents, and degree of nonlinearity. One of these techniques is the Poincare plot. This technique was first used as a qualitative tool and later, the quantification of the Poincare plot geometry was proposed. Tulppo *et al* [12] fit an ellipse to the shape of the Poincare plot in order to calculate heart rate indices. Brennan *et al* [1] demonstrate that the width of the Poincare plot indicates the level of short-term variability in heart rate signals.

A number of variations have been proposed, in order to optimize the use of the Poincare plot as a quantitative tool [1][2]. One of these is the lagged Poincare plot. The conventional plot has two dimensions and a lag of 1 interval, i.e., each point on the plot consists of a pair of successive

intervals (RR_i, RR_{i+1}). Lerma *et al* [7] used longer lags (RR_i, RR_{i+t} with $1 \leq t \leq 8$) to analyse HRV in chronic renal failure patients. Contreras *et al* [2] showed that lagged Poincare widths and spectral indices might be useful to distinguish normal from pathological heart rate signals. Thakre and Smith [11] used lags from 1 to 10 for heart rate analysis in patients with chronic heart failure.

The present study was aimed to assess the width of the Poincare plot with different lags on heart rate signals during meditation. For this purpose, heart rate signals of two groups of subjects (before meditation and during meditation) were collected. Poincare plots with six different lags (1–6) were constructed and the width of the Poincare plot for each lag was calculated.

II. METHOD

A. Data Collection

This study involved the heart rate signals of 25 healthy women. Fifteen subjects: 11 meditators (mean age 40.18 ± 7.19 , mean meditation experience 5 to 7 years) and 4 non meditators (mean age 25.5 ± 1.91) were asked to do meditation by listening to the guidance of the master. The other ten subjects were asked to do meditation by themselves. They were considered to be at an advanced level of meditation training (mean meditation experience 7 years, mean age 37.8 ± 6.39). All subjects were in good general health and did not follow any specific heart diseases or psychological disorders. They were asked to not eat any salty or fat foods before meditation practices or data recording. Informed written consent was obtained from each subject after the experimental procedures had been explained.

The experimental procedure was divided into two different stages: Subjects were first instructed to sit quietly for 5 minutes and kept their eyes closed. After that, they performed meditation. Meditation prescribes a certain bodily posture. They sit on a cushion 5 to 10 centimetres thick that is placed on blanket. They cross their legs so that one foot rests on the opposite thigh with the sole of their foot turned up and with their knees touching the blanket (lotus or half-lotus position). The torso should be kept straight, but it should not be strained. The head should be kept high with eyes closed. During this session, the meditators sat quietly and focusing on the breath.

The ECG signals (lead I) of all subjects were recorded in meditation clinic using 16-channel PowerLab (manufactured by ADInstruments). Heart rate signals were extracted online using Chart5 for Windows software. The monitoring system hardware filters band passed data in range 0.1-200 Hz for ECG time series. A digital notch filter was applied to the data

at 50Hz to remove any artefacts caused by alternating current line noise. The sampling rate was 400Hz.

B. Poincare Plots

Poincare plot is a geometrical representation of a time series in a Cartesian plane. A two dimensional plot constructed by plotting consecutive points is a representation of RR time series on phase space or Cartesian plane [3].

A standard Poincare plot of RR interval is shown in Figure 1. Two basic descriptors of the plot are SD1 and SD2. The line of identity is the 45° imaginary diagonal line on the Poincare plot and the points falling on the imaginary line has the property $RR_n = RR_{n+1}$. SD1 measures the dispersion of points perpendicular to the line of identity, whereas SD2 measures the dispersion along the line of identity. Fundamentally, SD1 and SD2 of Poincare plot is directly related to the basic statistical measures, standard deviation of RR interval (SDRR), and standard deviation of the successive difference of RR interval (SDSD), which is given by the relation shown in equation (1) and equation (2).

$$SD_1^2 = \frac{1}{2} SDSD^2 = \gamma_{RR}(0) - \gamma_{RR}(1) \quad (1)$$

$$SD_2^2 = 2SDRR^2 - \frac{1}{2} SDSD^2 = \gamma_{RR}(0) + \gamma_{RR}(1) - 2\overline{RR}^2 \quad (2)$$

where $\gamma_{RR}(0)$ and $\gamma_{RR}(1)$ is the autocorrelation function for lag-0 and lag-1 RR interval and \overline{RR} is the mean of RR intervals.

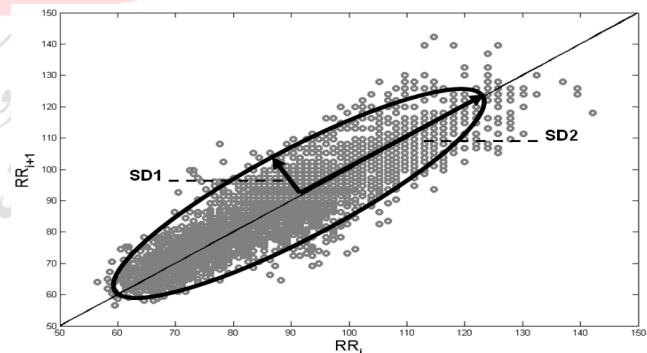


Figure 1. Standard Poincare plot. A standard Poincare plot (lag-1) of RR intervals before meditation (record C3). SD1 and SD2 represent the dispersion along minor and major axis of the fitted ellipse.

From equations (1) and (2), it is clear that the measures SD1 and SD2 are actually derived from the correlation and mean of the RR intervals time series with lag-0 and lag-1. The above equation sets are derived for unit time delay Poincare plot. Researchers have shown interest in plots with different time delays to get a better insight in the time-series signal. Usually the time delay is multiple of the cycle length or the

sampling time of the signal [1]. The dependency among the variables is controlled by the choice of time delay, and the most conventional analysis is performed with higher order linear correlation between points.

In case of plotting the 2D phase space with lag- m the equations for SD1 and SD2 can be represented as:

$$SD_1^2 = \gamma_{RR}(0) - \gamma_{RR}(m) \quad (3)$$

$$\Rightarrow SD_1 = F(\gamma_{RR}(0), \gamma_{RR}(m))$$

$$SD_2^2 = \gamma_{RR}(0) + \gamma_{RR}(m) - 2\overline{RR}^2 \quad (4)$$

$$\Rightarrow SD_2 = F(\gamma_{RR}(0), \gamma_{RR}(m))$$

where $\gamma_{RR}(m)$ is the autocorrelation function for lag- m RR interval. This implies that the standard descriptors for any arbitrary m lag Poincare plot is a function of autocorrelation of the signal at lag-0 and lag- m .

III. RESULTS

HRV signals (before and during meditation) are shown in Figure 2. During meditation signals become more periodic and their chaotic behaviour was decreased. According to Figure 2, total HR oscillation amplitude increased and the frequency of it decreased significantly during meditation. The mean of heart rate signals also decreased during meditation.

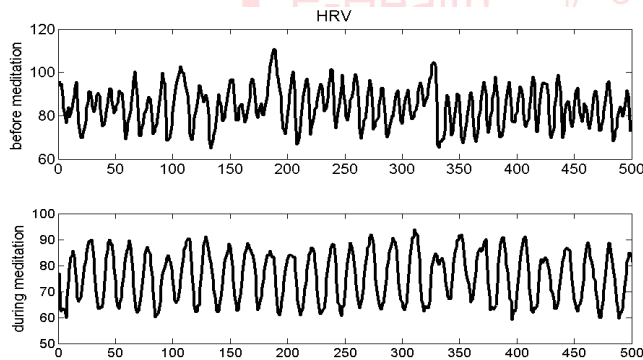


Figure 2. Heart rate variability (record C1): (top) before meditation (bottom) during meditation.

Poincare plots with six different lags (1–6) were constructed and the width of the Poincare plot for each lag was calculated. The Poincare plot with lag-1 of heart rate signals before and during meditation is shown in Figure 3(a) and Figure 3(b), respectively. Figure 3(c) and Figure 3(d) show the underlying temporal dynamics of 20 points of the same RR intervals before and during meditation.

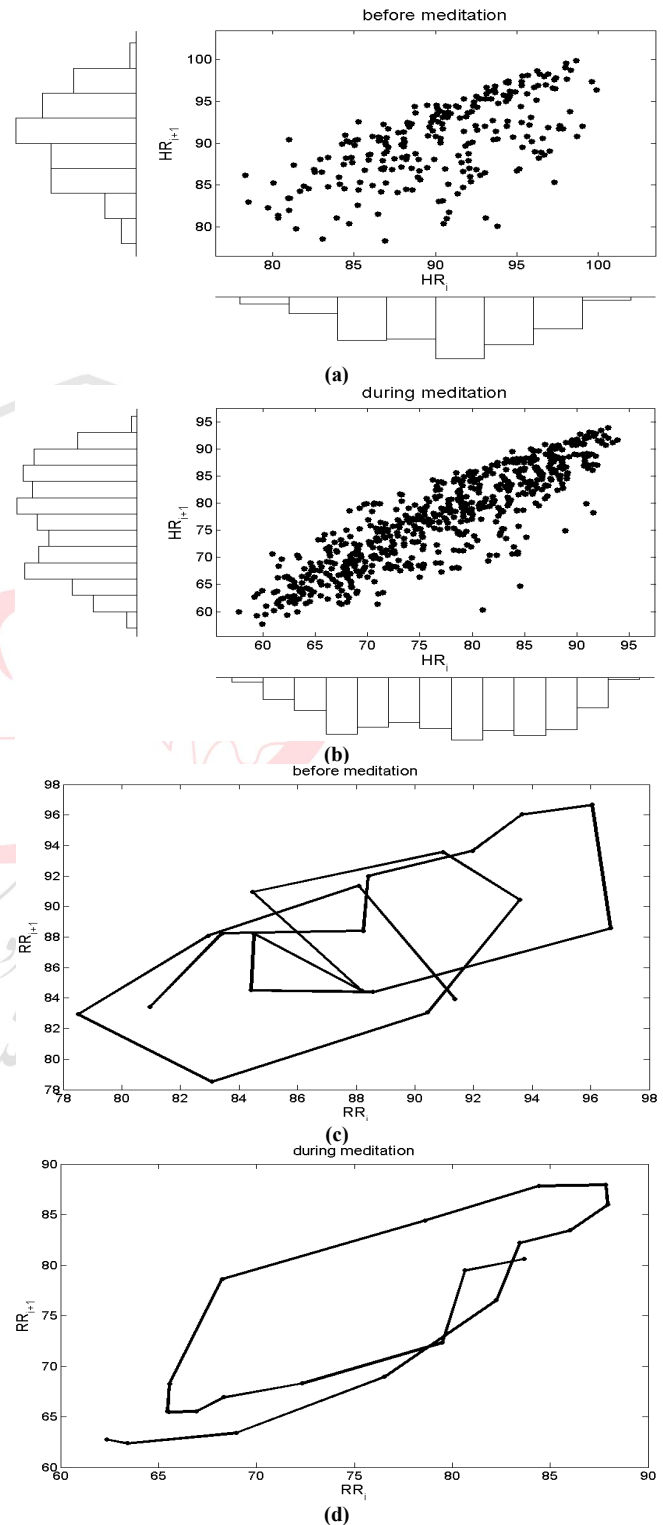


Figure 3. (a) A Poincare plot with lag-1 of RR intervals before meditation. (b) A Poincare plot with lag-1 of RR intervals during meditation. (c), (d) The underlying temporal dynamics of 20 points of the same RR intervals before and during meditation.

As shown in Figure 3(a) and Figure 3(b), there is a significant difference between two measure of the transversal and longitudinal dispersion of the cloud of points in Poincare plots. Figure 3(c) shows the chaotic behaviour of the heart rate signals before meditation and Figure 3(d) shows that the behaviour of heart rate signals becomes quasi periodic during meditation.

For purpose of comparison, Figure 4(a) and Figure 4(b) show the Poincare plots with lag 6 for the same records as in Figure 3(a) and Figure 3(b). Note that as the lag increases the shape of the plots becomes more circular during meditation.

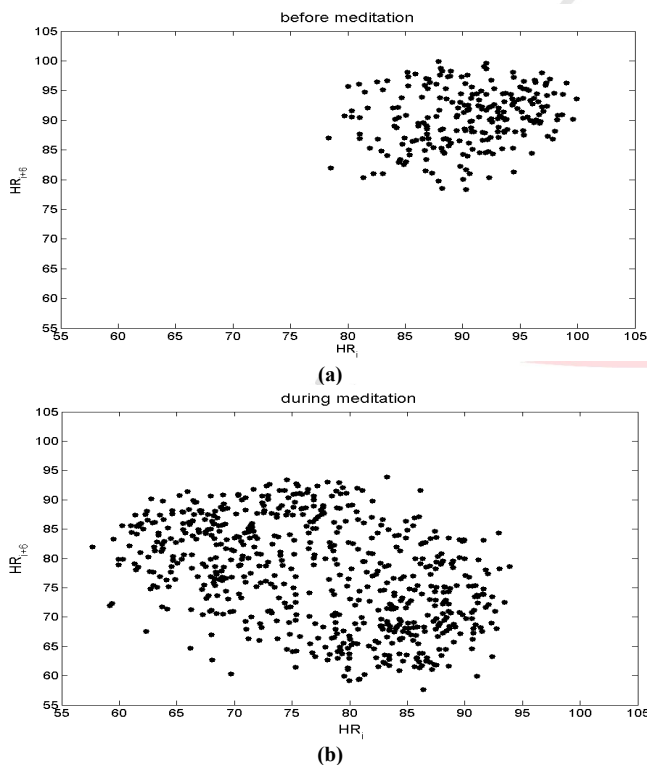


Figure 4. (a) A Poincare plot with lag-6 of RR intervals before meditation. (b) A Poincare plot with lag-6 of RR intervals during meditation.

After we constructed Poincare plots, SD1 was calculated for each lag. During meditation, the mean value of SD1 for Poincare plot with lag-1 was 2.5 ± 0.88 and with lag-6 was 4.77 ± 2.5 for all subjects. Figure 5 shows the influence of

different lags on SD1 within each group. In both groups, SD1 tended to increase as the lag increased.

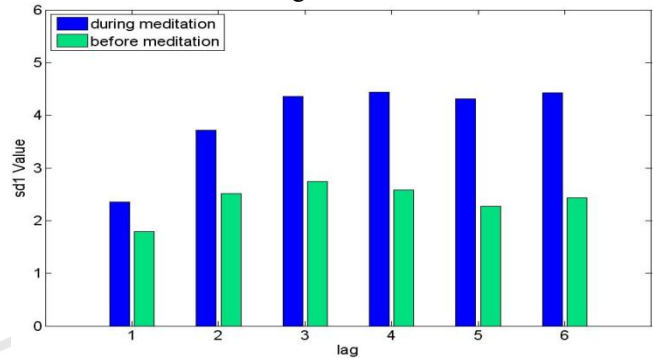


Figure 5. SD1 for different lags (1-6) in RR intervals before and during meditation (record C1).

SD1 of all subjects in two different lags (1 and 6) during meditation are shown in Figure 6. As shown in Figure 5 and Figure 6, the relative changes of SD1 with increasing lags were also significantly higher during meditation than before meditation.

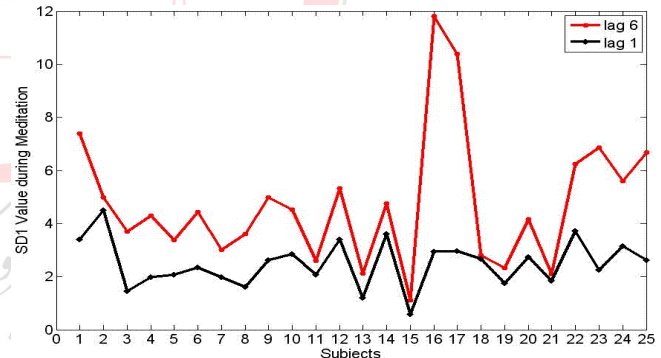


Figure 6. SD1 plot for two different lags (1 and 6) during meditation.

IV. CONCLUSIONS

It has shown that total HR oscillation amplitude increased and the frequency of it decreased significantly during meditation. These results on heart rate were similar to those in previous meditation studies [6]. Furthermore the mean of heart rate signals also decreased during meditation (Figure 2).

In this study, we examined the influence of different lags on the Poincare plots of heart rate signals in the specific psycho-physiological state. The results show that the Poincare plots have different shape during meditation. The Poincare plots are cigar-shaped plots for lag 1 (Figure 3(b)), whereas round clouds of points are shown for lag 6 (Figure 4(b)). The reason of this change is, when intervals are

plotted against immediately preceding intervals (lag-1), the correlation between these will be higher than if they were more widely separated. Cigar-shaped plots are typical of high correlation, whereas round clouds of points are typical of lack of correlation.

When comparing the SD1 value of Poincare plots between the experienced and non-experienced groups did not show any significant difference. Therefore both groups were almost similar in SD1 scores.

On a lag-1 Poincare plot, SD1 measures the variability from one heartbeat to the next. However, when we consider SD1 from Poincare plots with longer lags, the term of the variability is extended, from one heartbeat to another separated from it by many beats. The longer the distance between these beats, the higher the mean time interval between the Poincare plot points which are being summarized by SD1. Brennan *et al* [1], suggested that the Poincare plot width might reflect parasympathetic nervous system activity. According to Karmakar *et al* [3], the fluctuations of SD1 variability were also very high in the case of arrhythmias.

In this study, we have shown that SD1 tended to increase as the lag increased (Figure 5). According to Figure 5, the rate of changes in SD1 with increasing lags was also significantly higher during meditation than before meditation.

In conclusion, the comparative dynamic measures of the lagged Poincare plots during and before meditation give more insight of the heart rate signals in a specific psychophysiological state. The difference between lagged responses during meditation in comparison with before meditation might be useful to analysis heart rate signals during meditation.

These changes provide supplementary information about parasympathetic activity of cardiovascular system under the autonomic nervous system.

Other indices of Poincare plots like the ratio SD1/SD2 or asymmetry in the Poincare plot can be studied in future. Furthermore, the influence of different lags on Poincare plots during meditation could be analysed in other biological signals like electroencephalogram and respiration.

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