Dynamics of Heart Rate Changes following Moderate and High Volume Exercise Training

Chandan Karmakar[1], Ahsan Khandoker[2], Mikko Tulppo[3], Timo Makikallio[4], Antti Kiviniemi[3], Arto Hautala[3], Heikki Huikuri[4], Marimuthu Palaniswami[1], Herbert F Jelinek[5]

[1]The University of Melbourne, Melbourne, Australia
[2]Khalifa University of Science, Technology and Research, Abudhabi, UAE
[3]Department of Exercise and Medical Physiology, Verve, Oulu, Finland
[4]Division of Cardiology, Department of Medicine, University of Oulu, Oulu, Finland
[5]Charles Sturt University, NSW 2640, Australia

Abstract

In this study, we use the complex correlation method derived from the Poincaré map along with standard SD1 and SD2 parameters to obtain a better understanding of the relationship between optimal autonomic control of the heart rate and the correlation to fitness and exercise. Fifty participants were randomized into a moderate-volume (n=19), high-volume (n=15) and control group (n=16). The duration of the signal is divided into Day (9am-6pm), Night (12am -6am) and 24h groups. Standard Poincaré based parameters of heart rate variability SD1, SD2, SD1/SD2 and complex correlation measure (CCM) was calculated for each subject and duration. CCM indicated that there was a greater change associated with moderate volume exercise (median ± iqr 19.96 ± 29.62 vs 14.76 ± 23.14) compared to high volume exercise during the Day with both being significantly different to control (p<0.05). We conclude that autonomic balance and heart rate variability affects day time function more so than night time function, as metabolic and physiological processes slow down during the night.

1. Introduction

The effect of various exercise protocols on heart rate variability (HRV), a measure of autonomic modulation of heart, has been shown by a number of research groups. Diverse exercise models are used in high performance sports as well as for the general population to optimise fitness and health [1-3]. Applying different intensities for exercise or volume are the two main alternatives. Typically, exercise training results in increased HRV, indicating increased cardiac vagal activity, as measured by traditional time and frequency domain methods [4, 5].

Poincaré plot is a popular tool for visualizing the beat-to-beat variability of the heart rate. It reveals patterns of heart rate dynamics resulting from underlying nonlinear processes [6, 7]. However, standard descriptors of Poincaré plot (SD1 and SD2) measure the linear variability of the heart rate time series rather the dynamics [7]. The CCM method (Figure 1 (B)) measures the dynamics of the heart rate signal as a function of beat-to-beat changes rather than the global dynamics provided by SD1 and SD2. CCM is reported as a better indicator in indentifying cardiac pathology than standard Poincare descriptors [8].

Another important phenomenon of heart rate time series is the influence of current beat on subsequent beats. Lerma et al. [9] has reported that the current heart beat influences approximately eight beats downstream. In another study [10], the authors have showed that there is a curvilinear relationship between lag Poincaré plot indices for normal subjects, which is lost in Congestive Heart Failure (CHF) patients. Therefore, measuring multiple lag correlation provides more insight into the system rather than conventional measurements of variability of Poincaré plot. Since CCM is a function of multiple lag correlation, it captures information about such dynamics of heart rate.

In this study, we used the complex correlation method (CCM) derived from the Poincaré map along with standard parameters to obtain a better understanding how adaptations in cardiac autonomic function by exercise training are manifested with temporal changes in beat-to-beat HRV.

2. Methods

2.1. Standard Poincaré based HRV parameters

The Poincaré Plot is a nonlinear method proposed by several researchers [11-13] The Poincaré Plot allows determining linear components of the inter-beat variability and provides a quantitative measure of the temporal dynamics of the R-R interval [8,14, 15].

Typically, short-term (SD1) and long-term (SD2) fluctuations of the investigated system and the ratio SD1/SD2 indices are calculated from Poincaré plot analysis (Figure 1(A)). An ellipse can be drawn into the plot along the line of identity whereas the centre represents the mean value of the time series and the axes are SD1 and SD2. Although, Poincaré plot is a nonlinear method, these indices appear insensitive to the nonlinear characteristics of the RR intervals [7]. Let the RR intervals time series RR be defined as:

$$RR \equiv (RR_1, RR_2, \ldots, RR_N)$$

where N is the number RR intervals. The i-th point of the Poincaré plot is the duplet (RR_i, RR_{i+1}) and the parameters SD1 and SD2 are calculated using following equations:

$$SD1 = \sqrt{VAR\left(\frac{RR_i - RR_{i+1}}{\sqrt{2}}\right)}$$

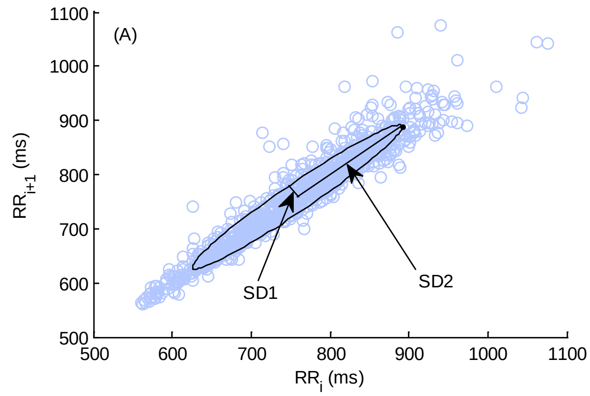
$$SD2 = \sqrt{VAR\left(\frac{RR_i + RR_{i+1}}{\sqrt{2}}\right)}$$

2.2. Complex Correlation Measure (CCM)

An extension of the Poincaré Plot is the complex correlation method (CCM), which determines and measures the temporal dynamics over the recording interval. Karmakar et al. proposed a novel Complex Correlation Measure (CCM) to quantify the change in dynamics of the Poincaré plot (Figure 1(B)) [8]. The CCM measures the point-to-point variation of the signal rather than gross description of the Poincaré plot. It is computed in a windowed manner, which embeds the temporal information of the signal. A moving window of three consecutive points from the Poincaré plot is considered and the temporal variation of the points is measured. If three points are aligned on a line then the value of the variation is zero, which represents the linear alignment of the points. If the Poincaré plot is composed of N points then the temporal variation of the plot is composed of all overlapping three point windows and can be calculated as:

$$CCM = \frac{1}{C_n(N-2)} \sum_{i=1}^{n-2} \|A(i)\|$$

where $A(i)$ represents area of the i-th triangle and C_n is the normalizing constant which is defined as, $C_n = \pi * SD1 * SD2$, represents the area of the fitted ellipse over Poincaré plot. The detail mathematical formulation of CCM is reported in our previous study [8].



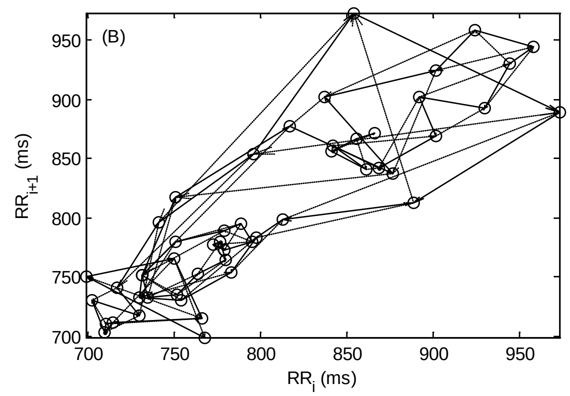


Figure 1. (A) Standard Poincaré plot and its descriptors. (B) Change in dynamics of Poincaré plot points measured by CCM.

2.3. Subjects and ECGs

Fifty participants were randomized into a moderate-volume (6 x 30 min per week, n=19), high-volume (6 x 60 min per week, n=15) and control group (n=16) after exclusions due to ectopic beats and contraindications for a maximal exercise test. The subjects underwent 24h ambulatory recording of R-R intervals before and after the 8-weeks training intervention. In this study, we divided the duration of the signal into Day (9am-6pm), Night (12am -6am) and 24h groups.

The R-R intervals were recorded over 24 h with Polar R-R Recorder (Polar Electro, Kempele, Finland) at an accuracy of 1 ms [16] and saved in a computer for further analysis of HRV. All R-R intervals were edited by visual inspection based on electrocardiogram (ECG) portions, to exclude all the undesirable beats, which accounted for <2% in every subject. Subjects were asked to go to bed before midnight and to stay in bed until 6 AM on the R-R interval recording days. The R-R intervals were recorded during a non-exercise day before and after training intervention. At the end of training intervention, the R-R intervals were recorded after a 48-hour non-exercise period.

2.4. Percentage change (Δ) of HRV parameters and statistics

Both ECG and exercise parameters of each subject were measured before and after the training protocol. As a result we have, HRV and exercise parameters for pre- and post-training stages. The percentage change of each parameter is calculated using following equation:

$$\Delta x = \frac{x_{post} - x_{pre}}{x_{pre}} \times 100$$

where, x is HRV or exercise parameter, x_{pre} is the parameter value before training and x_{post} is the parameter value after training.

The difference between the three groups was analyzed using the nonparametric Kruskal-Wallis test followed by a post hoc analysis. A p value of <0.05 was considered significant. MATLAB Statistics toolbox was used to perform all statistical operations.

Table 1: Percentage change of Poincaré based heart rate variability parameter over 24h after intervention.

		Moderate Training (n=19)	High Training (n=15)	Control (n=16)
ΔSD1 (%)	Day‡	38.30 ± 38.69	33.43 ± 36.38	0.64 ± 25.06^{a,b}
	Night	25.45 ± 43.41	24.01 ± 48.57	5.06 ± 48.29
	24h‡	28.69 ± 37.19	37.09 ± 44.73	3.10 ± 31.78^{a,b}
ΔSD2 (%)	Day	21.91 ± 23.23	27.67 ± 29.88	6.94 ± 30.48
	Night#	18.23 ± 17.37	24.94 ± 31.88	-0.79 ± 25.47^{a,b}
	24h	7.30 ± 19.93	10.96 ± 30.11	0.86 ± 20.60
ΔRatio (%)	Day#	9.14 ± 29.95	12.32 ± 16.23	-9.21 ± 30.32^{a,b}
	Night	5.87 ± 22.21	1.33 ± 37.98	-2.22 ± 43.79
	24h†	15.23 ± 25.05	21.12 ± 23.75	-0.08 ± 19.89^{a,b}
ΔCCM (%)	Day†	19.96 ± 29.62	14.76 ± 23.14	-7.98 ± 32.09^{a,b}
	Night	2.24 ± 36.96	8.47 ± 32.59	-3.85 ± 38.37
	24h†	17.09 ± 28.00	20.28 ± 35.89	-5.75 ± 28.72^{a,b}

Values are medians ± iqr. #p<0.05; †p<0.01; ‡p<0.001: among three groups. a: p<0.05 between control and moderate volume training group; b: p<0.05 between control and high volume training group.

3. Results and discussions

Tulppo et al. previously reported that moderate and high volume training resulted in similar changes in the time and frequency domain HRV parameters with autonomic regulation increasing towards a vagal dominance after aerobic training [17].

The lack of temporal information is the primary limitation of the standard descriptors of the Poincaré plot. SD1and SD2 represents the distribution of signal in 2D space and carries only spatial (shape) information. It should be noted that many possible RR interval series result in identical plot with exactly similar SD1 and SD2 values in spite of different temporal structure.

Median values of the change in HRV parameters following either moderate or high volume training for the current study are shown in Table 1. The change (Δ) in HRV parameters associated with the different training volumes and control over the 8-week test period were significantly different for the day and 24 hour period among the three groups except for ΔSD2, which showed a significant difference only for the night recording period. All HRV parameters increased in the post exercise condition for both the moderate and high training group. The post hoc tests found that ΔSD1 and ΔCCM for both training groups were significantly different to the control group during the day and night recording periods. However for the ΔSD1/SD2 measure such difference was only found for the 24h recording period.

Of interest is that the effects of moderate and high volume training on the Poincaré plot based parameters only indicated an effect during the day and 24h recording periods and not during the night time recording period. This indicates that the Poincaré plot and CCM measures are sensitive to autonomic regulation of the heart beat during higher physiological and psychological active periods. Night time measures of the effect of exercise were not different to the control group as the body moves towards a more stable homeostasis.

The value of CCM decreases with increased autocorrelation of the plot. In arrhythmia, the pattern of the Poincaré plots becomes more complex [8] and thus reducing the correlation of the signal. In case of healthy subjects the value of CCM is lower than that of arrhythmic subjects.

Both moderate and high volume exercise increase the autocorrelation and thus move the system to a vagal predominance during daytime hours indicating an improved physiological and psychological basis.

6. Conclusions

We conclude that autonomic balance and heart rate variability affects day time function more so than night time function, when metabolic and physiological processes slow down. The complex correlation method has shown that including a temporal dynamics measure provides additional information to describe the sympatho-vagal balance and the effect of different levels of exercise with respect to control.

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Address for correspondence.

Chandan Karmakar
Research Fellow
Department of Electrical & Electronic Engineering
University of Melbourne
Parkville, Melbourne, VIC 3010, Australia
karmakar@unimelb.edu.au