Changes in Heart Rate Circadian Rhythm following Exercise in Middle-Aged Men

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Abstract

Aerobic fitness and exercise have been associated with improved cardiovascular health. Health effects of exercise may be associated with the circadian rhythm of the heart and may specifically reduced the risk of heart attacks during high-risk periods over the 24 hours. Linear and nonlinear heart rate variability (HRV) measures indicate the degree of heart rate modulation by the parasympathetic and sympathetic branches of the autonomic nervous system. Twenty-one sedentary middle-aged men underwent an 8-week moderate-volume exercise program and 24-hour heart rate recordings were obtained prior and following the exercise period. Temporal dynamic changes over the 24-hour period were calculated using the complex correlation measure (CCM) derived from the Poincaré Plot and analyzed in 1-hour intervals. The maximum significant differences between pre and post moderate-volume exercise were between the morning hours of 8.30 to 9.30 AM (p= 0.011) and in the afternoon between 4.00 and 5.00 PM (p=0.021). In the morning the temporal dynamics (mean ± sd) increased from 0.1±0.02 to 0.15±0.06. In the afternoon period the increase was from 0.11±0.04 to 0.14±0.05. An increase in CCM indicates a more complex temporal dynamics of the heart rate and an improved parasympathetic influence.

1. Introduction

The autonomic nervous system is a key component in integrating visceral and central nervous system function. Autonomic dysregulation associated either with loss of parasympathetic or an increased sympathetic output increases the risk of cardiovascular morbidity and mortality [1]. Aerobic fitness and exercise have been associated with changes in heart rate variability (HRV) and improved cardiovascular outcome [2, 3]. The extent of sympathetic and parasympathetic contribution to heart rhythm and the effect of exercise can be investigated using heart rate variability [3, 4].

Current measures of the autonomic balance of heart rate regulation include time and frequency domain as well as nonlinear measures [5, 6]. Time and frequency domain measures provide a global characterization of the heart rate variability over the recording interval. To obtain a better understanding of the relationship between optimal autonomic control of the heart rate and the correlation to exercise a more dynamic measure of heart rate is required. An extension of the Poincaré plot is the complex correlation method (CCM), which relies on computing the point-to-point variation of the signal rather than gross description and thus provides a temporal resolution [7]. The present study aimed at applying CCM for analysis of the circadian rhythm changes over a 24-hour R-R interval tachogram of sedentary individuals participating in a low volume exercise regimen. Circadian rhythm analysis provides additional information with respect to hourly changes in the temporal dynamics measured as CCM [8].

2. Data & Methods

2.1. Subjects

Thirty-nine subjects were recruited to the Department of Exercise and Medical Physiology, Verve Research, Oulu, Finland for diverse training modalities. Standard exclusion criteria were applied and included smoking, obesity, diabetes, cardiorespiratory disease, or participated in regular physical training. Data was obtained from 19 participants of a moderate-volume training group after exclusions for noncompliance (motivation and leg problems) and presence of ectopic beats in the ECG recordings. Ethics approval was obtained from the Merikoski Rehabilitation and

Research Center (Oulu, Finland) Ethics Committee, and all subjects gave written informed consent.

2.2. Protocol

The training period lasted 8 weeks and included six 30-min sessions per week for the moderate-volume training group at an intensity of 70–80% of maximum HR. The training mode was walking and jogging. The R-R intervals were recorded with Polar R-R Recorder (Polar Electro, Kempele, Finland) at an accuracy of one millisecond.

2.3. ECG preprocessing

All R-R intervals were edited by visual inspection for ectopic beats, which accounted for less than 2% in every recording. The measures of R-R interval dynamics were calculated from the entire 24-h recording and divided into hourly segments to detect possible circadian differences.

2.4. Poincaré plot analysis

Typically, short-term (SD1) and long-term (SD2) fluctuations and the ratio SD1/SD2 are calculated from the Poincaré Plot [9]. From the Poincaré Plot, the Complex Correlation Measure (CCM), which measures the point-to-point variation of the signal can be derived [10]. Let the RR intervals time series RR be defined as:

$$RR \equiv (RR_1, RR_2, RR_3 \dots, RR_N)$$

where, N is the number RR intervals. A standard Poincaré plot of RR interval is shown in Figure 1a. Two basic descriptors of the plot are $SD1$ and $SD2$. The line of identity is the 45° imaginary diagonal line on the Poincaré 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. $SD1$ and $SD2$ are the second moment measure of the distribution of points forming the Poincaré plot and can be defined as:

$$SD1^2 = \frac{1}{N-1}\sum_{i=1}^{N-1}(D_i')^2$$
$$SD2^2 = \frac{1}{N-1}\sum_{i=1}^{N-1}(D_i'')^2 \qquad (1)$$

where D_i' and D_i'' are the distances of any point from the line of identity ($RR_n = RR_{n+1}$) and the line perpendicular to the line of identity ($RR_n + RR_{n+1} = 2\overline{RR}$). Here, $\overline{RR}$ represents the mean of RR interval time series and can be expressed as:

$$D_i' = \frac{1}{\sqrt{2}}|RR_n - RR_{n+1}|$$
$$D_i'' = \frac{1}{\sqrt{2}}|RR_n + RR_{n+1} - 2\overline{RR}| \qquad (2)$$

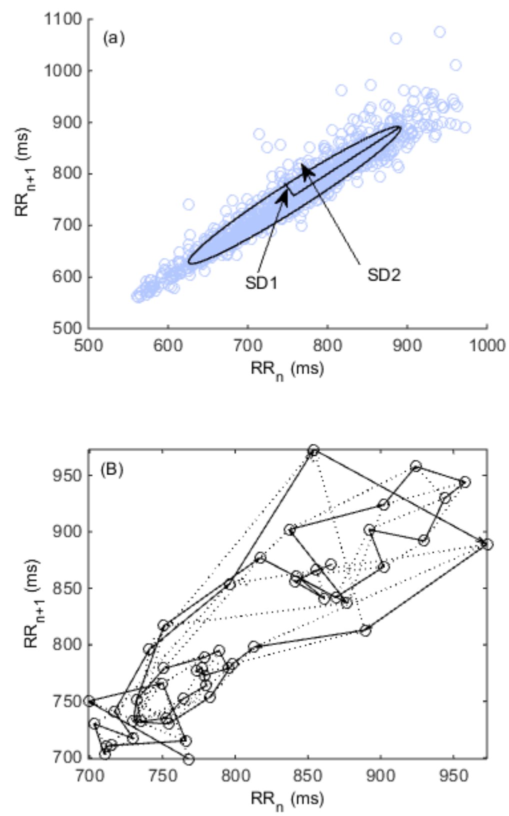

Figure 1. Standar *lag-1* Poincaré plot and its descriptors (a); Change in dynamics of Poincaré plot points measured by CCM (b).

Besides $SD1$ and $SD2$, we have also used the ratio, $SD1/SD2$, as another parameter. The standard descriptors SD1 and SD2 are linear statistics and hence the measures do not directly quantify the nonlinear temporal variations in the time series contained in the Poincaré plot. To measure the change in temporal dynamics of Poincare plot, Karmakar et al. proposed a novel index Complex Correlation Measure (CCM) to quantify the change in dynamics of the Poincaré plot (Figure 1b) [10]. 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, termed as CCM, is composed of all overlapping three point windows and can be calculated as:

$$CCM = \frac{1}{C_n(N-2)} \sum_{i=1}^{n-2} \|A(i)\| \quad (3)$$

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 [17].

2.5. Cosinor analysis

Cosinor fitting by least squares is a mathematical technique to describe circadian data. A 24-hour cosine function is fitted to the original data to obtain three indices being the midline-estimating statistic of rhythm (MESOR), the amplitude (Amp) and the acrophase (AC) [11]. In the current study, we applied cosinor analysis to Poincaré HRV parameters. The hourly values of these HRV parameters were used as the original data to fit the cosine function. Finally, indices were calculated for each subject both pre and post exercise. To remove inter-subject variation we used the percentage amplitude ($Amp\%$) parameter, which was calculated as $Amp\% = \frac{Amp}{M} \times 100$. Moreover, for easy understanding, the acrophase (AC) was converted to clock hour. In this study, we considered 12 AM as the zero phase and the AC value was calculate using this as a reference. Each clock hour is equivalent to $(360/24)^o = 15^o$ and the clock hour calculated from the acrophase.

3. Results

Circadian rhythm changes over the 24-hour recording period are shown in Figure 1 for the Poincaré Plot HRV parameters. Figure 1 shows the circadian rhythm changes prior and following moderate-volume training. The sections highlighted in turquoise indicate times of either sympathetic surges or parasympathetic withdrawal and constitute high-risk times for heart attacks. These possible high-risk periods for adverse cardiac events are augmented following moderate-volume exercise.

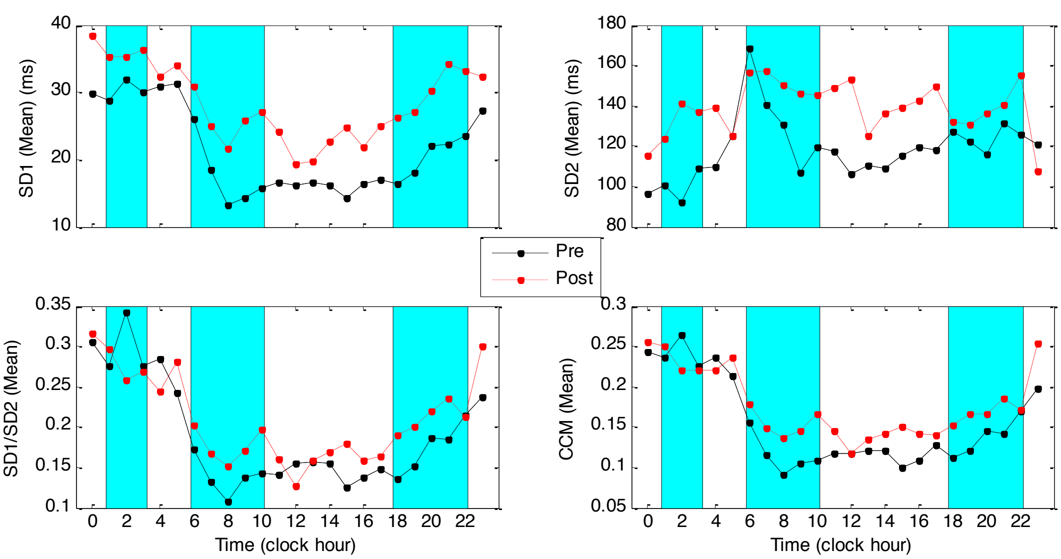

Figure 1: circadian rhythm changes prior and following moderate-volume training.

Cosinor analysis is a common model for analyzing circadian rhythms and confirmed our findings applied to Poincaré associated HRV parameters [12]. For moderate exercise volume Amp% derived from SD1, SD1/SD2 and CCM shifted from a time period prior to maximal risk (before 6 AM) to the second quarter of the day between 6 AM and 9 AM. In contrast no change in the time the peaks in Amp% was seen for SD2 (Table 1).

4. Discussion

Heart rate and HRV are not constant over 24 hours and change with internal and external environmental demands. There are two main peaks associated with increased risk of heart attack at 8 AM and 6 PM [13]. Exercise therapy has been shown to improve HRV in cardiovascular disease by increasing parasympathetic influence and reducing sympathetic tone [14].

Moderate-volume training effect on HRV was observed within the morning and afternoon high risk periods but not for the time between midnight and 2 AM, which as been suggested as a high risk period in men in the under-65 age group [8,13,15]. The increase in CCM, which may be indicative of an improved cardiac temporal dynamics and hence a reduction in possible arrhythmic events suggests a vagal predominance re-emerging during these time periods.

Cosinor analysis indicated that the maximal activity of SD1 and CCM parameters move from a peak in the 1st quarter to the 2nd quarter of the day and increased in the 3rd quarter, coinciding with the periods of highest cardiac event vulnerability [16].

5. Conclusion

Cosinor modeling of the temporal dynamics with CCM derived from the Poincaré Plot indicted a positive effect following an 8 weeks moderate-volume exercise. The important and unexpected finding is that the most significant differences were observed at times when the risk of a heart attack is greatest in men in the morning and afternoon and that moderate-volume exercise may augment risk of adverse cardiac events in the highest risk periods.

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