

Responses of the geometric indices of heart rate variability to the active orthostatic test in women

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OBJECTIVES: The effects of the orthostatic test on the cardiovascular system have been investigated, but there are no data on the behavior of the geometric indices of heart rate variability. We evaluated the effects of the active orthostatic test on the geometric indices of heart rate variability in women.

METHOD: The study was performed on 12 healthy women between ages 18 and 30. For the analysis of heart rate variability, heart rate was recorded beat-to-beat. The RR intervals were transformed into geometric figures, and from these we calculated the triangular index, the triangular interpolation of RR intervals, the SD1, SD2 indexes and the SD1/SD2 ratio, which were obtained from the Poincaré plot. Visual analysis of the plot was also performed. For the test, participants quickly stood up from a seated position in 3 seconds or less, and remained standing still for 15 minutes. Heart rate variability samples were collected at four moments: rest, 0-5 minutes, 5-10 minutes and 10-15 minutes at standing position.

RESULTS: The triangular index, the triangular interpolation of RR intervals, the SD1 and SD2 indices were reduced ($p < 0.05$) at 10-15 minutes after the volunteers stood up from seated position. The SD1/SD2 ratio was decreased at 0-15 minutes after the subjects changed from seated to orthostatic position.

CONCLUSION: The geometric indices of heart rate variability decreased in response to the active orthostatic test in healthy women.

KEYWORDS: Autonomic Nervous System; Cardiovascular System; Nonlinear Dynamics; Physiology.

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INTRODUCTION

The autonomic nervous system regulates the cardiovascular system, and its dysfunction characterizes some pathological conditions.¹⁻³ Heart rate variability (HRV) describes the complex regulatory system interaction between heart rate and the autonomic nervous system. This is a conventionally accepted term to describe the fluctuations in the intervals between consecutive heartbeats (RR intervals), which are known to be controlled by the sinus node.⁴

Methods used for HRV analysis include the geometric methods, namely the triangular index (RRtri), the triangular interpolation of NN interval histogram (TINN) and the Poincaré plot, which converts RR intervals into geometric patterns and allows an analysis of HRV through the geometric or graphic properties of the resulting pattern.⁵

The RRtri and TINN are calculated from the construction of a histogram of density of normal RR intervals, which contains (on the "x" axis) the length of RR intervals, and (on the "y" axis), the frequency with which they occurred. Joining the points of the histogram columns results in a triangle from which these indexes may be extracted.^{6,7}

The Poincaré plot is a two-dimensional graphic representation of the correlation between consecutive RR intervals, in which each interval is plotted against the following interval. Its analysis can be done qualitatively by assessing the shape formed by its attractor, which shows the degree of complexity of RR intervals, or quantitatively, by fitting an ellipse to the shape formed by the plot, from which the following indexes are produced: SD1, SD2 and the SD1/SD2 ratio.⁸ Moreover, the analysis of the Poincaré plot is considered by some experts as based on nonlinear dynamics.⁸

HRV analysis by means of nonlinear methods has been gaining increasing interest, since there is evidence that the mechanisms involved in cardiovascular regulation probably interact in a nonlinear way.⁸

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Cardiovascular evaluation tests may provide relevant information about the adequate function of the autonomic nervous system and about the functional capacity of effectors (heart and vessels) and other associated structures. One common cardiovascular test used in clinical practice is the orthostatic test, which is based on the measurement of heart rate reflex changes in response to adequate stimuli; this test may be applied passively or actively. Application of cardiovascular tests may be used for the study of cardiovascular system control in healthy subjects as well as in adult patients with different diagnoses of autonomic dysregulation.⁹

Previous studies investigated spectral analysis of HRV in response to the Active Orthostatic Test.^{10,11} Nevertheless, nothing is known regarding the effects of this test on the geometric indices of HRV and the recovery of the indices. The understanding of the physiological responses induced by autonomic tests is important to develop future therapies and to prevent cardiovascular disorders. Therefore, we investigated the effects of the Active Orthostatic Test on the geometric indices of HRV in healthy women.

■ METHODS

Study Population

We analyzed 12 healthy female subjects aged between 18 and 30 years, selected from our Institution. All of them were volunteers and were informed about the procedures and objectives of the study and, after agreeing, signed a term of informed consent. All study procedures were approved by the Ethics Committee in Research of the Faculty of Sciences of the Universidade Estadual Paulista, Campus of Marília (Case No. CEP-2011-382); the entire procedure followed the procedures laid down by Resolution 196/96, National Health Council, dated 10/10/1996.

Exclusion criteria

We considered the following exclusion criteria: cardiopulmonary disorders, neurological and other impairments that prevent the subject to perform the procedures, and treatment with drugs that influence cardiac autonomic regulation.

Initial Evaluation

Before the experimental procedure, volunteers were identified through the following information: age, gender, weight, height and body mass index (BMI). Anthropometric measurements were obtained according to Lohman et al.¹² Weight was determined by using a digital scale (W 200/5, Welmy, Brazil) with a precision of 0.1kg. Height was determined by using a stadiometer (ES 2020, Sanny, Brazil) with a precision of 0.1 cm and 2.20 m of extension. Body mass index was calculated using the formula $BMI = \text{weight (kg)} / \text{height (m)}^2$. We also measured systolic and diastolic blood pressure and heart rate.

Experimental protocol

Data were collected in our laboratory under controlled temperature (21°C–25°C) and humidity (50%–60%); volunteers were instructed to avoid consuming alcohol, caffeine and substances that influence the autonomic nervous system for 24 hours before evaluation. Data were collected between 8:00 and 12:00 a.m. in order to cancel the interference of circadian rhythms. All procedures necessary

for the data collection were explained to the participants, and the subjects were instructed to remain at rest and to avoid talking during the data collection.

After the initial evaluation, the heart monitor strap was placed on each subject's thorax over the distal third of the sternum. The HR receiver (Polar RS800CX monitor, Polar Electro OY, Kempele, Finland) was placed on the wrist.

The subjects remained seated, breathing spontaneously for 10 minutes. After this rest, they quickly stood up from the seated position in 3 seconds or less in response to a verbal command and remained standing for 15 minutes.

HRV analysis

The R-R intervals recorded by the portable heart rate monitor (with a sampling rate of 1000 Hz) were downloaded to the Polar Precision Performance program (v. 3.0, Polar Electro, Finland). The software enabled the visualization of heart rate and the extraction of a cardiac period (R-R interval) file in "txt" format. Following digital filtering complemented with manual filtering for the elimination of premature ectopic beats and artifacts, at least 256 R-R intervals were used for the data analysis. Only those series with more than 95% sinus rhythm was included in the study.^{13,14} Heart rate variability samples were collected in the following moments: seated rest with spontaneous breathing, 0-5 minutes, 5-10 minutes, and 10-15 minutes at standing position. For calculation of the indices we used the HRV Analysis software (Kubios HRV v.1.1 for Windows, Biomedical Signal Analysis Group, Department of Applied Physics, University of Kuopio, Finland).¹⁵

Geometric indices of HRV

HRV analysis was performed by means of geometrical methods: RRtri, TINN and Poincaré plot (SD1, SD2, SD1/SD2 ratio).

The RRtri was calculated from a constructed density histogram of RR intervals, which contains, on the horizontal axis, all possible values of RR intervals measured on a discrete scale with 7.8125 ms boxes (1/128 seconds); on the vertical axis, the plot contained the frequencies with which each value occurred. The union of points of the histogram columns creates a triangular shape. The RRtri was obtained by dividing the total number of RR intervals used to construct the histogram by their modal frequency (RR interval value that most frequently appeared on RR).¹⁶

The TINN consists of the measure of the base of a triangle. The method of least squares is used to determine the triangle.⁴ The RRtri and the TINN express the overall variability of RR intervals.⁴

The Poincaré plot is a map of points in Cartesian coordinates, constructed from the values of RR intervals obtained, where each point is represented on an "x" axis (horizontal/abscissa) by the previous normal RR interval, and on a "y" axis (vertical/ordinate), by the following RR interval.

For quantitative analysis of the plot, an ellipse was fitted to the points of the chart, with the center determined by the average RR intervals. The SD1 indexes were calculated to measure the standard deviation of the distances of the points to the diagonal $y = x$, and SD2 measures the standard deviation of the distances of points to the line $y = -x + RR_m$, where RR_m is the average of RR intervals.

The SD1 is an index of instantaneous recording of the variability of beat-to-beat and represents parasympathetic

activity, while SD2 is an index that represents HRV in long-term records, and reflects the overall variability. Their ratio (SD1/SD2) shows the ratio between short and long variations of RR intervals.^{17,18}

The qualitative analysis of the plot was made through the analysis of the figures formed by its attractor, which as described by Tulppo et al.¹⁹ in (a) a figure in which an increase in the dispersion of RR intervals is observed with increased intervals, characteristic of a normal plot; (b) a small figure with beat-to-beat global dispersion without increased dispersion of RR intervals in the long term.

Statistical Analysis

Standard statistical methods were used for the calculation of means and standard deviations. Normal Gaussian distribution of the data was verified by the Shapiro-Wilk goodness-of-fit test (z value >1.0). For parametric distributions, we applied ANOVA for repeated measures followed by the Bonferroni post test (SDNN, alpha-2 and alpha-1/alpha-2). For non-parametric distributions, we used the Friedman test followed by the Dunn’s test (RMSSD, pNN50, LF, HF, LF/HF and alpha-1). We compared the HRV indices between the four moments (seated rest vs. 0-5 min after the volunteers stood up, vs. 5-10 min after the volunteers stood up, and vs. 10-15 min after the volunteers stood up). Differences were considered significant when the probability of a Type I error was less than 5% (p < 0.05). We used the Software GraphPad StatMate version 2.00 for Windows, GraphPad Software, San Diego California USA.

RESULTS

Table 1 presents the values regarding basal diastolic and systolic arterial pressure, heart rate, mean RR, weight, height and body mass index of the volunteers. All volunteers exhibited normal parameters. The mean RR and mean HR indicate that the volunteers were not athletes.

Table 2 presents data related to the geometric indices before and after the subjects stood up. All indices were reduced after the change from seated to standing. RRtri, TINN, SD1 and SD2 were reduced at 10-15 minutes after the volunteers stood up (seated control vs. 10-15 minutes) while the SD1/SD2 ratio was decreased at the three investigated moments (seated control vs. 0-5 minutes vs. 5-10 minutes vs. 10-15 minutes).

Figure 1 presents examples of Poincaré plot patterns drawn from one patient for the four moments evaluated. Figure 1A shows a good dispersion of points, characteristics of a normal plot, whereas 1B, 1C and 1D show a decrease in

Table 1 - Height, Weight, Body Mass Index, Baseline Systolic and diastolic arterial pressure, heart rate, and mean RR interval of 12 female volunteers enrolled in this study.

Parameter	Mean ± Std deviation
Height (m)	1.67 ± 0.03
Weight (kg)	54.6 ± 23
Body Mass Index (kg/m ²)	21.2 ± 2
Systolic Arterial Pressure (mmHg)	101.3 ± 16
Diastolic Arterial Pressure (mmHg)	78 ± 11
Heart Rate (bpm)	75.4 ± 8
Mean RR (ms)	761.6 ± 81

Table 2 - Mean and standard deviation for geometric indices of HRV between before and after volunteers stood up. RRtri: triangular index; TINN: triangular interpolation of RR intervals; SD1; SD2 and SD1/SD2 ratio.

Index	Control	0-5 min	5-10 min	10-15 min	p
RRtri	13.1 ± 5	11.1 ± 4	8.6 ± 5	*7.2 ± 3	0.012
TINN	201.3 ± 23	200.4 ± 54	172 ± 60	*150 ± 39	0.031
SD1	22 ± 8	13.9 ± 6	12.6 ± 6	*11.8 ± 4	0.015
SD2	58.8 ± 15	62 ± 11	53.2 ± 11	*47 ± 10	0.038
SD1/SD2	0.34 ± 0.2	*0.22 ± 0.09	*0.22 ± 0.08	*0.24 ± 0.06	0.0023

*p < 0.05: Vs. Control

dispersion, characterizing a reduction in HRV and an increase in the sympathetic component.

DISCUSSION

Our investigation aimed to evaluate the behavior of the geometric indices of HRV in response to the Active Orthostatic Test. We report that the RRtri, TINN, SD1 and SD2 indices were reduced at 10-15 minutes after the volunteers stood up. The SD1/SD2 ratio was decreased over the entire 15 minutes after the subjects changed from seated to standing. Our findings support the concept that the geometric indices of HRV are a reliable tool of measurements to evaluate the orthostatic test.

The reduced values of SD1 at 10-15 minutes after the volunteers stood up indicate reduced parasympathetic activity at that time. This index measures short-term HRV and represents the transverse axis of the Poincaré plot. It also corresponds to the standard deviation of the instantaneous variability of heart rate beat-by-beat.²⁰ And it indicates the parasympathetic influence on the sinoatrial node.²¹ Considering the reaction of this index to the change from seated to standing, we suggest that the parasympathetic activity reduction in response to this physiological stimulation is more intense at 10-15 minutes after the participants stood up.

Similarly, the SD2 index, which is related to the global HRV, was also decreased at 10-15 minutes after the subjects stood up from the seated position. The physiological significance of the SD2 index is less well-defined compared with the SD1 index. This index is thought to be related to the continuous long-term variability of the R-R interval.²² Variables that characterize the Active Orthostatic Test are mostly expressed by sympathetic and vagal influences on the heart rate.⁹ Our study supports the idea that the SD1 and SD2 indices are valuable markers for the Active Orthostatic Test evaluation.

The visual analysis (qualitative) of the Poincaré plot indicated reduction of HRV mainly during the first 10 minutes after the volunteers stood up. Nevertheless, SD1, SD2, TINN and RRtri indices were reduced at 10-15 minutes. The dynamics of the cardiac autonomic regulation is assumed to be nonlinear. Consequently, nonlinear methods have been applied to the analysis of HRV.²² The Poincaré plot, also known as Lorenz plot, is one of these techniques.⁸ As previously mentioned, it is a scatterplot of each RR interval as a function of the previous one. This method was first used as a qualitative instrument.⁸ and later, the quantification of the Poincaré plot geometry was proposed. Specifically, Tulppo et al (1996)¹⁷ fit an ellipse to the shape of the Poincaré plot to calculate HRV indices, for

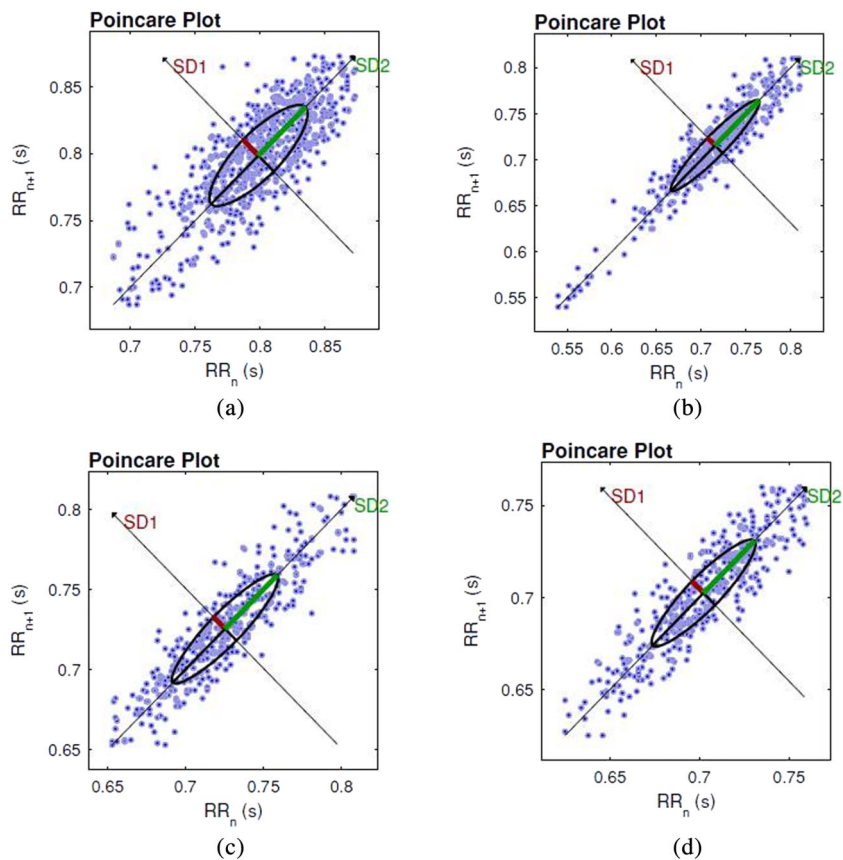


Figure 1 - Visual pattern of Poincaré plot observed in one subject at seated position (1A), 0-5 minutes after the subjects stood up (1B) 5-10 minutes after the subjects stood up (1C) and 10-15 minutes after the subjects stood up (1D). 1A shows a good dispersion of points, characteristics of a normal plot, whereas 1B, 1C and 1D show a decrease in dispersion, characterizing a reduction in HRV and increase in the sympathetic activity.

instance, the standard deviation of instantaneous beat-to-beat RR interval variability, or SD1. Taken together, it is possible that the Poincaré plot, although a subjective method, may be more sensitive than the quantitative geometric analysis of HRV in response to the Active Orthostatic Test.

According to our data, the geometric indices of HRV were significantly changed at 10-15 minutes after the volunteers stood up from seated position. Clinical application of autonomic tests, such as the Active Orthostatic Test, may be used for cardiovascular system examination study in healthy individuals and also in patients with different diseases.⁹ However, to the best of our knowledge, no previous study investigated the physiological responses of the geometric indices of HRV during a period after change from seated to orthostatic position. In this study we suggest that in healthy women the more intense responses occur at 10-15 minutes after the volunteer stood up.

The comprehension of the mechanisms involved in the autonomic cardiovascular tests helps to correctly interpret the results. Our findings are important to support the analysis of the geometric indices of HRV in response to the Active Orthostatic Test, a well-recognized autonomic test.²³ The Poincaré plot was also found to be a good marker for

autonomic change in response to the change from seated to orthostatic position.

We should address a limitation of our study that is the small population based on women health students. In this circumstance, we should be careful when extrapolating data to different population.

CONCLUSION

The geometric indices of HRV were reduced in response to the Active Orthostatic Test in healthy women. We believe that the qualitative analysis is more sensitive than the quantitative analysis in this autonomic test.

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RESUMO

OBJETIVOS: Os efeitos do teste ortostático sobre o sistema cardiovascular já foram investigados, mas não há dados sobre o comportamento dos índices geométricos de variabilidade da frequência cardíaca. Aqui, foram avaliados os

efeitos do teste ortostático ativo nos índices geométricos de variabilidade da frequência cardíaca em mulheres.

MÉTODO: O estudo foi realizado em 12 mulheres saudáveis com idades entre 18 e 30 anos. Para a análise da variabilidade da frequência cardíaca, este parâmetro foi registrado batimento a batimento. Os intervalos RR foram transformados em figuras geométricas e, a partir destas, foi calculado o índice triangular, a interpolação triangular dos intervalos RR, o SD1, SD2 e a relação SD1/SD2, que foram obtidos a partir da plotagem de Poincaré. A análise visual do gráfico foi também realizada. Para o teste, os participantes levantaram-se rapidamente de uma posição sentada (em 3 segundos ou menos) e permaneceram imóveis, de pé, por 15 minutos. Amostras de variação de frequência cardíaca foram coletadas em quatro momentos: repouso, 0-5 minutos, 5-10 minutos e 10-15 minutos a pé.

RESULTADOS: O índice triangular, a interpolação triangular dos intervalos RR, o SD1 e SD2 índices apresentaram-se reduzidos ($p < 0,05$) no intervalo 10-15 minutos depois de os voluntários se levantarem. A relação SD1/SD2 apresentou-se reduzida durante o intervalo 0-15 minutos depois dos participantes passarem à posição ortostática.

CONCLUSÃO: Os índices geométricos de variabilidade da frequência cardíaca diminuíram em resposta ao teste ortostático ativo em mulheres saudáveis.

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