GEOMETRIC AND LINEAR INDICES OF HEART RATE VARIABILITY DURING AN EXERCISE WITH FLEXIBLE POLE

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Aim. Evaluate the acute effects of a standardized exercise with flexible pole on cardiac autonomic regulation.

Material and methods. We evaluated 23 women between 18 and 25 years old and heart rate variability (HRV) was analyzed in the time (SDNN, RMSSD and pNN50), frequency domain (HF, LF and LF/HF ratio) and geometric analysis (RRTri, TINN, SD1, SD2 and SD1/SD2). The subjects remained at rest for 10 minutes. After the rest period, the volunteers performed the exercises with the flexible poles. Immediately after the exercise protocol, the volunteers remained seated at rest for 60 minutes and HRV were analyzed.

Results. We observed no significant changes in the time domain and frequency domain indices of HRV between before and after single bout of exercise with flexible pole.

Conclusion. A single bout of exercise with flexible pole did not induce significant change in geometric and linear indices of HRV.

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Key words: cardiovascular system, autonomic nervous system, exercise therapy.

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HRV — heart rate variability, DAP — diastolic arterial pressure, SAP — systolic arterial pressure, IPAQ — International Physical Activity Questionnaire, BMI — body mass index, HR — heart rate, SDNN — standard deviation of normal-to-normal R-R intervals, pNN50 — percentage of adjacent RR intervals with a difference of duration greater than 50ms, RMSSD — root-mean square of differences between adjacent normal RR intervals in a time interval, LF — low frequency, VLF — very low frequency, HF — high frequency, LF/HF — low frequency/high frequency ratio.

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ГЕОМЕТРИЧЕСКИЕ И ЛИНЕЙНЫЕ ПОКАЗАТЕЛИ ВАРИАБЕЛЬНОСТИ СЕРДЕЧНОГО РИТМА ВО ВРЕМЯ УПРАЖНЕНИЙ С ГИБКИМ ШЕСТОМ

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Цель. Оценка острого воздействия стандартизированного упражнения с гибким шестом на кардиальную вегетативную регуляцию.

Материал и методы. Мы оценивали 23 женщин в возрасте от 18 до 25 лет и анализировали вариабельность их сердечного ритма (ВСР) во временной области (SDNN, RMSSD и pNN50), в частотной области (соотношение HF, LF и LF/HF) и проводили геометрический анализ (RRTri, TINN, SD1, SD2 и SD1/SD2). Испытуемые оставались в покое в течение 10 минут. После периода отдыха, добровольцы выполняли упражнения с гибкими шестами. Сразу после осуществления протокола, волонтеры оставались сидеть в покое в течение 60 минут и их ВСР анализировалась.

Результаты. Мы не наблюдали никаких изменений значения во временной области и частотной области показателей ВСР между до и после одного круга с упражнений с гибким шестом.

Заключение. Один круг упражнений с гибким шестом не вызвать значительные изменения в геометрических и линейных показателях ВСР.

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Ключевые слова: сердечно-сосудистая система, вегетативная нервная система, лечебная физкультура.

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Specific changes are necessary to maintain cardiac system homeostasis during exercise activity. Those responses are promoted by the action of the autonomic nervous system on the heart [1]. The usual cardiac autonomic reaction to exercise presents abrupt parasympathetic withdrawal during the beginning of exercise leading to heart rate increase and following increase in the sympathetic nervous system activity. After exercise cessation heart rate reduces due to the vagal reactivation mechanism [2].

Cardiac autonomic regulation can be evaluated through heart rate variability (HRV) is a well recognized non-invasive method. HRV evaluates the oscillations in the intervals between consecutive heart beats (RR intervals) that are associated with the influences of the autonomic nervous system on the sinus node [3]. Alterations in HRV after exercise are featured by reduced vagal tone and global variability of HRV and progressive increase in HRV [4].

A recent instrument that is used for musculoskeletal rehabilitation is the flexible pole. It is an instrument that permits muscle contractions generated by co-contraction of the muscle groups of the upper limb [5], inducing isometric contractions of the shoulder and trunk muscles [6, 7].

Although flexible pole exercise has been used in musculoskeletal rehabilitation programs [6], to the best of our knowledge, no study concerning its effects on autonomic nervous system was found in the literature. Moreover, isometric contractions were shown to change parasympathetic component of HRV [8]. In this circumstance, we endeavored to evaluate the acute effects of a standardized exercise with flexible pole on cardiac autonomic regulation.

Material and methods

Study Population. Subjects were 23 healthy female students, all nonsmokers, aged between 18 and 25 years. All volunteers were informed about the procedures and objectives of the study and gave written 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 Marilia (No. 0554-2012), and were in accordance with Resolution 196/96 National Health 10/10/1996.

Non-inclusion criteria. We did not include subjects that reported the following conditions: cardiopulmonary, psychological, neurological related disorders and other impairments that prevent the subject known to perform procedures, and treatment with drugs that influence cardiac autonomic regulation. Volunteers were not evaluated on 10-15 days and 20-25 days after the first day of the menstrual cycle [9]. We also excluded physically active subjects according to the International Physical Activity Questionnaire (IPAQ) [10].

Initial Evaluation. Prior to the study, baseline criteria included: age, gender, weight, height and body mass index (BMI). Weight was determined using a digital scale (W 200/5, Welmy, Brazil) with a precision of 0,1 kg. Height was determined using a stadiometer (ES 2020, Sanny, Brazil) with a precision of 0,1 cm and 2,20 m of extension. Body mass index (BMI) was calculated as weight / height^2, with weight in kilograms and height in meters [11, 12].

HRV analysis. The R-R intervals recorded by the portable RS800CX heart rate (HR) 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 HR 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 series with more than 95% sinus rhythm was included in the study [3]. For calculation of the linear 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) [11, 12].

We used Kubios HRV version 2.0 software to analyze all HRV indices.

Linear indices and Geometric analysis of HRV. To analyse HRV in the frequency domain, the low frequency (LF=0,04–0,15 Hz) and high frequency (HF=0,15–0,40 Hz) spectral components were used in ms^2 and normalized units (nu), representing a value relative to each spectral component in relation to the total power minus the very low frequency (VLF) components, and the ratio between these components (LF/HF). The spectral analysis was calculated using the Fast Fourier Transform algorithm [11-13].

The analysis in the time domain was performed in terms of SDNN (standard deviation of normal-to-normal R-R intervals), pNN50 (percentage of adjacent RR intervals with a difference of duration greater than 50 ms) and RMSSD (root-mean square of differences between adjacent normal RR intervals in a time interval) [11-13].

The geometric analysis was performed using the following geometrical methods: RRtri, TINN and Poincaré plot (SD1, SD2 and SD1/SD2 ratio). The RRtri was calculated from the construction of a density histogram of RR intervals, which contains the horizontal axis of all possible RR intervals measured on a discrete scale with 7,8125 ms boxes (1/128 seconds) and on the vertical axis, the frequency with which each occurred. The union of points of the histogram columns forms a triangle-like shape. The RRtri was obtained by dividing the number of RR intervals used to construct the histogram by their modal frequency (i.e., the RR interval that most frequently appeared on RR) [11-13].

The TINN consists of the measure of the base of a triangle. The method of least squares is used to determine the triangle. The RRtri and the TINN express the overall variability of the RR intervals [3].

The Poincaré plot is a map of points in Cartesian coordinates that is constructed from the values of the RR intervals. Each point is represented on the x-axis by the previous normal RR interval and on the y-axis by the following RR interval [3, 11, 12].

For the quantitative analysis of the plot, an ellipse was fitted to the points of the chart, with the center determined by the average RR interval. The SD1 indices were calculated to measure the standard deviation of the distances of the points from the diagonal y=x, and SD2 measures the standard deviation of the distances of points from the line y=-x+RRm, where RRm is the average RR interval. The SD1 is an index of the instantaneous recording of the variability of beat-to-beat and represents the parasympathetic activity, whereas the SD2 index represents the long-term HRV and reflects the overall variability. The SD1/SD2 shows the ratio between the short- and long-term variation among the RR intervals [3].

The plot was qualitatively analyzed using HRV analysis software based on the figures formed by its attractor. The expected shapes were described by Tulppo et al. [14] as: figures in which an increase in the dispersion of RR intervals is observed with increased intervals, characteristic of a normal plot, and, small figures with beat-to-beat global dispersion without increased long-term dispersion of RR intervals [11, 12].

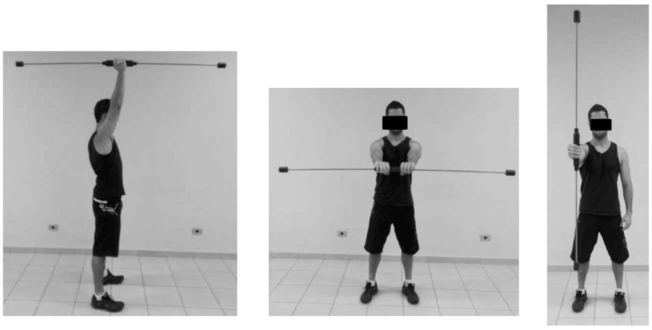
Protocol. Data collection was undertaken in the same sound-proof room for all volunteers with the temperature between 21°C and 25°C and relative humidity between 50 and 60% and volunteers were instructed not to drink alcohol and caffeine for 24 hours before evaluation. Data were collected on an individual basis, between 8 and 12 AM to standardize the protocol. All procedures necessary for the data collection were explained on an individual basis and the subjects were instructed to remain at rest and avoid talking during the collection [11, 12].

After the initial evaluation the heart monitor belt was then placed over the thorax, aligned with the distal third of the sternum and the Polar RS800CX heart rate receiver (Polar Electro®, Finland) was placed on the wrist. Before starting the exercises, the volunteers received visual feedback through a monitor to maintain neutral posture standing and were instructed to maintain the same posture throughout the exercise. Systolic and diastolic blood pressure was measured before, immediately after exercise and 60 minutes after exercise. The oscillatory movement of the flexible pole (Flexibar®) was held by flexion and elbow extension. The flexible pole vibrated at a frequency of 5 Hz, and the oscillation frequency of the flexible pole was based on an auditory stimulation through a metronome (Quartz Metronome®) calibrated at 300 bpm [11-15].

The exercises with the flexible pole were conducted with volunteers at standing position with feet apart (wide base) and shoulder flexion as the proposed position. To maintain the proper shoulder flexion in each upper limb it was used as a target visual feedback. All exercises were performed for 15 seconds with 50-60 seconds of rest between each exercise. Three repetitions were performed for each exercise [7].

The exercises were performed on three positions: 1) with one shoulder at approximately 180° of flexion with the flexible pole on the frontal plane, parallel to the ground (Figure 1A), 2) with two shoulders on 90° of flexion with the flexible pole on the transverse plane (Figure 1B), and 3) one shoulder at 90° of flexion with the flexible pole on the sagittal plane, perpendicular to the ground (Figure 1C). HRV was analyzed at the following periods: control rest, 0-5 min, 5-10 min, 10-15 min, 15-20 min, 20-25 min and 25-30 min after the protocol exercise [11, 12].

Statistical Analysis. Standard statistical methods were used to calculate the means and standard deviations. The normal Gaussian distribution of the data was verified by the Shapiro-Wilk goodness-of-fit test (z value of >1,0). For parametric distributions we applied ANOVA for repeated measures followed by the Bonferroni posttest. For non-parametric distributions we used the Friedman test followed by Dunn's posttest. Differences were considered significant when the probability of a Type I error was less than 5% ($p<0{,}05$). We used Biostat 2009 Professional 5.8.4 software.



A B C

Figure 1. Exercise protocol with flexible pole at the three positions: 1) with shoulders at approximately 180° of flexion with the flexible pole on the frontal plane, parallel to the ground (A); 2) with the shoulder on 90° of flexion with the flexible pole on the transverse plane (B); and 3) shoulders at 90° of flexion with the flexible pole on the sagittal plane, perpendicular to the ground (C).

Table 1

Data on baseline mean RR interval, age, height, body weight and body mass index of the volunteers

Variable	Value
Age (years)	20,4±2
Height (m)	1,72±0,05
Weight (kg)	72,9±5
BMI (kg/m^2)	25,05±2,6
HR (bpm)	81,7±11
Mean RR (ms)	752,8±117

Abbreviations: HR — baseline heart rate, Mean RR — mean RR interval, BMI — body mass index, m: meters, kg: kilograms, bpm: beats per minute, ms: milliseconds.

Results

Data on baseline mean RR interval, age, height, body weight and body mass index (BMI) are presented in Table 1.

We note the behavior of systolic and diastolic arterial blood pressure, HRV in the time and frequency domain indices before and after a single bout of exercise with flexible pole in Table 2. The SDNN, RMSSD and pNN50 indices in the time domain were not significantly changed after a standardized exercise with flexible pole and the frequency domain indices (LF: nu and ms^2; HF: nu and ms^2 and LF ratio) did not present significant responses induced by a single bout of exercise with flexible pole (Table 2).

According to Figure 2 we observe that the linear geometric indices of HRV (RRTri and TINN) were not significantly changed after one session of exercise with

Table 2

Diastolic and systolic arterial pressure before, time and frequency domain indices before and after a standardized exercise protocol with flexible pole

Variable	Rest	0-5min	5-10 min	10-15 min	15-20 min	20-25 min	25-30 min
SAP (mmHg)	112,3±10	114,3±10	-	-	-	-	110,6±11
DAP (mmHg)	78,3±9	75±10	-	-	-	-	77,8±10
LF (ms^2)	910±608	773±636	663±429	796±621	718±434	904±802	875±586
HF (ms^2)	455±318	407±504	418±423	467±459	439±448	478±441	507±472
LF (nu)	65,3±16	69,4±18	64,6±13	64,8±15	65,9±15	66,8±15	67,7±13
HF (nu)	34,6±16	30,5±18	35,3±13	35,4±15	34±15	33,1±15	32,2±13
LF/HF	3,2±4	3,28±2,3	2,33±1,49	2,87±3,2	2,64±1,81	3,08±2,6	2,61±1,41
SDNN	44,6±12	40,9±17	39,1±12	42,3±13	40,7±11	41,3±14	43,8±17
RMSSD	31,07±12	28,2±17	27±15	28,3±14	28,4±14	29,2±16	29,6±15
pNN50	12,4±10	10,2±14	8,9±11	10,2±11	9,7±11	10,3±12	10,7±11

Abbreviations: DAP — diastolic arterial pressure, SAP — systolic arterial pressure, SDNN — standard deviation of normal-to-normal R-R intervals, pNN50 — percentage of adjacent RR intervals with a difference of duration greater than 50ms, RMSSD — root-mean square of differences between adjacent normal RR intervals in a time interval, LF — low frequency, HF — high frequency, LF/HF — low frequency/high frequency ratio, ms — milliseconds, mmHg — millimeters of mercury.

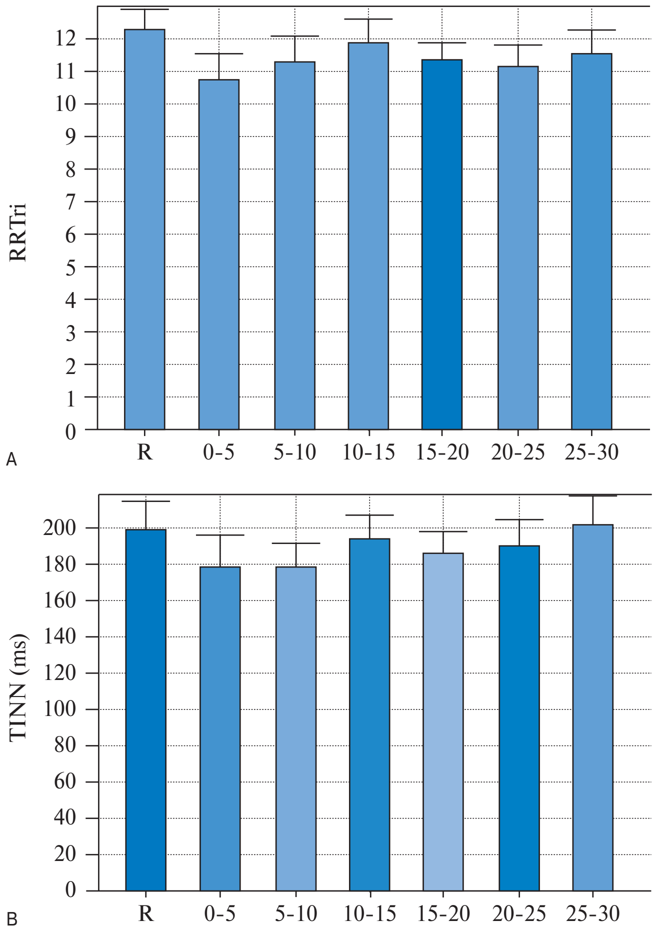


Figure 2. RRTri (A) and TINN (B) indices before and after standardized exercise protocol with flexible pole. RRTri: Triangular index; TINN: triangular interpolation of RR intervals.

flexible pole. Moreover, the Poincaré plot indices (SD1, SD2 and SD1/SD2 ratio) did not present significant between before and after the exercise protocol (Figure 3).

An example of the Poincaré plot patterns is presented in Figure 4. The plot is presented in one subject during the control condition before exercise (A), 0-5 min (B), 5-10 min (C), 10-15 min (D), 15-20 min (E), 20-25 min (F) and 25-30 min (G) after a standardized exercise protocol with flexible pole.

Discussion

The autonomic nervous system is influenced by isometric and rhythmic exercise, since the literature indicated that sympathetic outflow to the skin increases during this style of exercise [15-17]. Isometric leg extension and isometric handgrip were also reported to elicit cardiovascular responses characterized by increase in skin sympathetic nerve activity [18]. In this context, flexible pole is a tool used for rehabilitation therapies that induces isometric contraction of the shoulder and trunk muscles [7, 19]. In order to investigate a standardized protocol with this instrument for cardiac rehabilitation we evaluated the acute effects of a single bout of exercise with flexible pole on cardiac autonomic regulation. As a main finding, we observed that this standardized exercise protocol did not induce significant responses of diastolic and systolic arterial pressure and HRV indices analyzed in the time and frequency domain and also through analysis of geometric indices.

After endurance exercise it is observed the usual post-exercise hypotension, which is defined as a reduction of arterial blood pressure compared to the pre-exercise baseline levels [20]. A previous study reported that blood pressure was increased in young men during static exercise at 40% of maximal voluntary contraction [21]. The literature supports this result indicating that activation of the muscle chemoreflex during sustained isometric contractions increases blood pressure through increase in muscle sympathetic nerve activity [22]. However, based on our findings, there was no significant response of arterial blood pressure after the standardized exercise with oscillatory

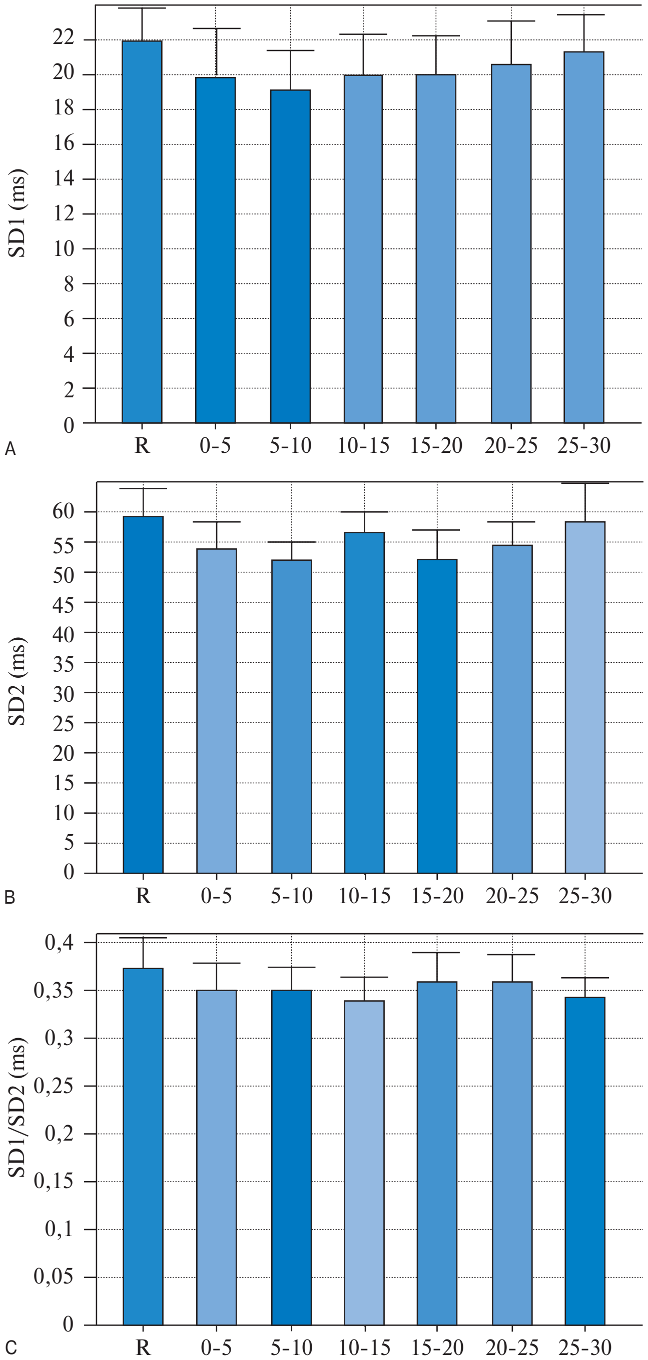


Figure 3. SD1 (A), SD2 (B) and SD1/SD2 (C) ratio before and after a standardized exercise protocol with flexible pole. SD1 — standard deviation of the instantaneous variability of the beat-to beat heart rate; SD2 — standard deviation of long-term continuous RR interval variability; SD1/SD2 ratio — ratio between the short — and long — term variations of RR intervals.

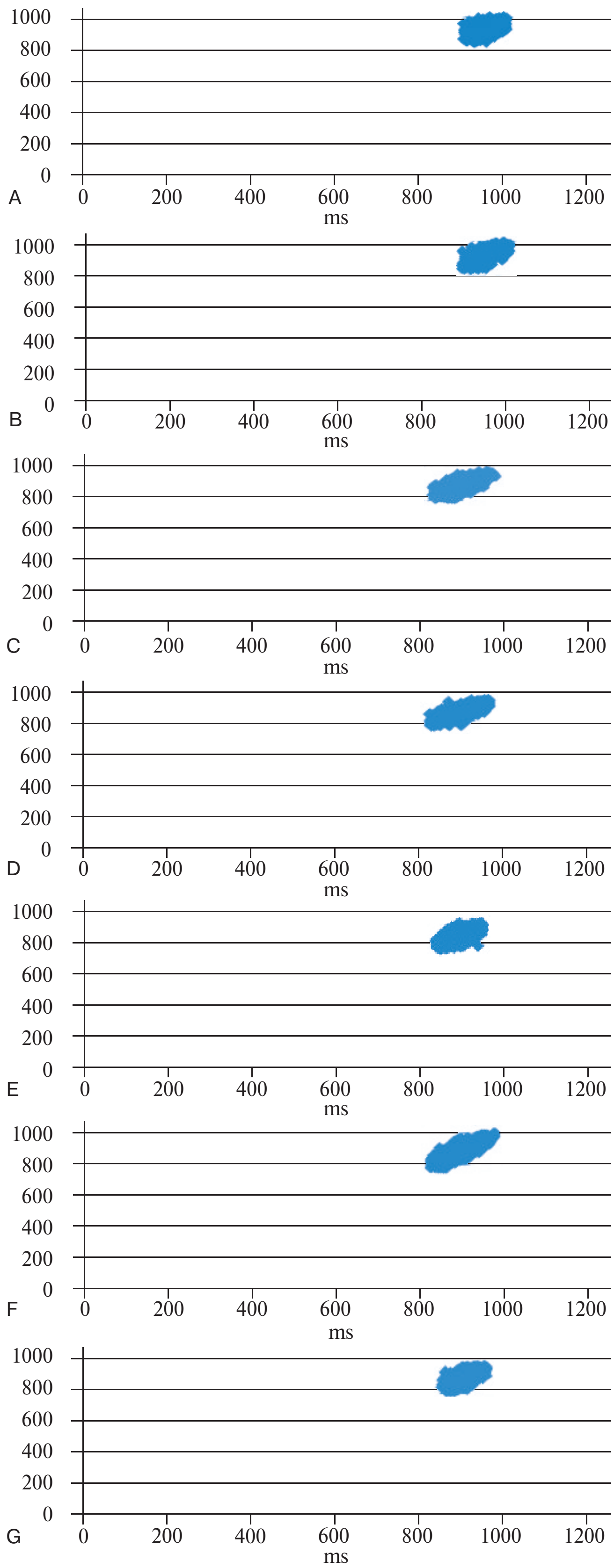


Figure 4. Visual pattern of the Poincaré plot observed in one subject during the control condition before exercise (A), 0-5 min (B), 5-10 min (C), 10-15 min (D), 15-20 min (E), 20-25 min (F) and 25-30 min (G) after a single bout of exercise with flexible pole.

pole. In this sense, we believe that the intensity of the protocol exercise used in our study that was based on previous investigation [7, 19], was the main explanation for the absence of significant responses of arterial pressure during the recovery phase.

We reported absence of significant cardiac autonomic responses induced by a single bout of standardized exercise with flexible pole. The literature indicated that endurance and strength exercises acutely elicit parasympathetic withdrawal during exercise and vagal reentrance immediately after exercise cessation [2]. Another investigation reported that cardiac autonomic control is not completely recovered within 30 minutes of acute endurance or resistance exercise [23]. This physiological response is based on central command and muscle chemoreflex, two mechanisms proposed to explain the typical pressor response to exercise. The central command is an efferent response triggered by parallel activation of the cardiovascular control centers and the motor cortex. The muscle chemoreflex is a reaction induced by chemosensitive afferent nerve fibers located in the exercising muscles [24]. Immediately after exercise cessation, there is a reduction of inputs from the central nervous system and from the receptors in skeletal muscle, leading to a sudden exponential decrease in heart rate, due to the vagal reactivation [25]. Nonetheless, this expected response was not observed in our study. We may conclude that this is due to the intensity of exercise that was based on auditory stimulation through a metronome calibrated at 300 bpm and also based on the period the subjects performed each exercise, i.e. 15 seconds.

HRV analysis was performed in the linear time and frequency domain indices as well as through Poincaré plot indices (SD1, SD2 and SD1/SD2 ratio). The SD1 index corresponds to the dispersion of points perpendicular to the line of identity and reflects the variability of short-term, it corresponds to the standard deviation of instantaneous beat to beat variability and is an indicator of vagal cardiac modulation. The SD2 index corresponds to the dispersion of the points along the line of identity and indicates the HRV in long-term record, indicating the standard deviation of long-term continuous RR intervals (RR+1) and is an indicator of sympathetic and parasympathetic cardiac modulation [23]. The Poincaré plot analysis is considered nonlinear because it analyzes the nonlinear dynamics of a phenomenon that is able to detect the hidden correlation patterns of a time series signal [27]. Nonlinear analysis is indicated to be related to the genesis of heart rate dynamics [28]. Moreover, this method of analysis of HRV is suggested to be more sensitivity to identify alterations in cardiac autonomic regulation compared to the linear analysis of HRV [28]. Although those indices that are more sensitive were not significantly changed between before and after exercise with flexible pole, we stimulate new studies to investigate the safety of this standardized exercise protocol in patients with cardiovascular diseases.

In our study we did not evaluate physically active subjects according to the International Physical Activity Questionnaire. A recent study demonstrated different recovery of cardiac autonomic regulation after a treadmill test until voluntary exhaustion between moderately trained and highly trained wrestlers. The authors reported that the SD1 index presented faster recovery in the moderate group compared to the high trained group [29].

Ogata et al [11] (2014) and Antonio et al [12] (2014) have performed a similar protocol with flexible pole, the authors conducted the study with young men and concluded that a single bout of exercise with a flexible pole reduced the HRV and parasympathetic recovery was observed approximately 30 min after exercise. In this context, Antonio et al conducted exercise with flexible pole in 32 young women, however, there were no significant differences between the indices of heart rate variability; the difference between these studies was the performance of the exercise, either using one arm sometimes with both arms. In our research we investigated the geometric indices (RRtri and TINN) of HRV and indices derived from the Poincaré plot (SD1, SD2 and SD1 / SD2 ratio). On the other hand, the analysis of these new indices showed no significant difference.

Another point to be raised in our study is that we evaluated only women in order to avoid sex-dependent effects on HRV responses induced by exercise. The literature indicated differences between women and men in relation to cardiac autonomic responses after a section of exercise [29]. In this sense, we should be careful when extrapolating this data to different population.

Exercises with flexible pole have been used as complementary tool to treat or improve shoulder muscles physical capacities in physical therapy rehabilitation programs [11, 12, 17]. Nevertheless, after an extensive review on Medline/Pubmed database, we observed that this is the first investigation to analyze the effects of a single bout of a standardized exercise with flexible pole on HRV in healthy adult women. Severe alterations in cardiac autonomic modulation elicited by stress or exercises can lead to cardiac events such as sudden death [11, 30], the maintenance of HRV after the intervention protocol supports the safety of this exercise style for patients with cardiovascular disorders.

Conclusion

A single bout of exercise with flexible pole did not elicit significant changes in geometric and linear indices of heart rate variability. Additional studies are suggested to evaluate the chronic effects of this exercise protocol.

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