GLOBAL CHAOTIC PARAMETERS OF HEART RATE VARIABILITY DURING EXPOSURE TO MUSICAL AUDITORY STIMULATION

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The physiological responses to auditory stimulation with music are relevant to understand and provide additional information regarding complementary and alternative therapies.

Aim. Investigate the acute effects of auditory stimulation on the globally chaotic parameters of Heart rate Variability (HRV).

Material and methods. 27 healthy male students. Measurements of the equivalent sound levels were conducted in a soundproof room. The RR-intervals recorded by the portable HR monitor. HRV was analysed in the following periods: control protocol — the 10-minutes period before the exposure and the 10-minutes period during the exposure to musical auditory stimulation**.**

Results. We have the values of CFP for seven groups for 27 subjects who are undergoing auditory stimulation; hence a grid of 7 by 27 to be assessed. The First Principal Component has a variance of 4,5282 and accounts for 64,7% of the total variance. The Second Principal Component has an eigenvalue of 2,4631 accounting for 99,9% of total variance. When we observe the results of PCA, CFP3 is very weakly influential with first principal component (PC1) at 0,012; whereas, CFP1 is much more influential with PC1 of 0,2288.

Conclusion. Musical auditory stimulation with a specific classic style did not acutely influence the global chaotic parameters of HRV.

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Key words: cardiovascular system, autonomic nervous system, audiology, chaos.

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BMI — body mass index, DFA — detrended fluctuation analysis, DBP — diastolic blood pressure, DPSS — discrete prolate spheroidal sequences, ECG — electrocardiographic, HR — heart rate, HRV — heart rate variability, MIRE — microphone in real ear, MTM — multi-taper method, PCA — principal component analysis, sDFA — spectral detrended fluctuation analysis, sMTM — spectral multi-taper method, SBP — systolic blood pressure, CFP — chaotic forward parameter.

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ГЛОБАЛЬНЫЕ ХАОТИЧЕСКИЕ ПАРАМЕТРЫ ВАРИАБЕЛЬНОСТИ РИТМА СЕРДЦА ВО ВРЕМЯ МУЗЫКАЛЬНОЙ ЗВУКОВОЙ СТИМУЛЯЦИИ

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Физиологический ответ на звуковую стимуляцию представляет интерес в плане дальнейшего применения в ряду дополнительных методов лечения.

Цель. Изучить острые эффекты звуковой стимуляции на глобальный хаотический показатель вариабельности ритма сердца (ВРС).

Материал и методы. Двадцать семь здоровых мужчин, студентов. Измерение эквивалентных уровней звука проводилось в акустически закрытом помещении. Интервалы RR записывались портативным монитором частоты сокращений. Анализ ВРС проводился в следующие периоды: контрольный — за 10 минут до экспозиции звука, и в 10-минутные периоды во время звуковой стимуляции.

Результаты. Получены хаотические показатели (CFP) в 7 группах, для 27 участников, подвергшихся звуковой стимуляции, то есть включена в анализ сетка 7x27. Первый главный компонент имеет дисперсию 4,5282 и отвечает за 64,7% общей дисперсии. Второй главный компонент имеет собственный вектор 2,4631, отвечая за 99,9% общей дисперсии. Когда рассматривали результаты анализа главного компонента, CFP3 очень слабо влиял на первый главный компонент в точке 0,012; тогда как CFP1 был очень влиятелен на первый главный компонент в 0,2288.

Заключение. Музыкальная слуховая стимуляция в классическом стиле не влияла на глобальные хаотические параметры ВРС в остром эксперименте.

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The physiological responses to auditory stimulation with music are relevant to understand and provide additional information regarding complementary and alternative therapies [1]. A previous study demonstrated that auditory stimulation with a relaxant music style two hours per day, two days per week during eight weeks improved the cardiac autonomic regulation of subjects treated with a cardio-toxic drug [2], however, its acute effects are still controversial [3, 4].

In this sense, cardiac inter-beat intervals normally fluctuate in a chaotic wave [5, 6]. Methods derived from statistical physics have motivated researchers to study this phenomenon [7]. The RR-interval of the Electrocardiographic (ECG) trace is necessary for such analysis.

Heart Rate Variability (HRV) analysis using non-linear dynamical techniques is becoming an important area of research. This mathematical analysis of human illness is often termed "dynamical disease study" [8]. Such analysis usually requires observation for days or weeks. Usually, changes in the HRV patterns are an indicator of health status. High HRV is a signal of good adaptation and characterize a healthy person with efficient autonomic mechanisms. Whilst lower HRV is frequently an indicator of abnormal and insufficient adaptation of the autonomic nervous system; causing the subject low physiological function [9].

Detrended fluctuation analysis (DFA) quantifies the presence or absence of fractal correlation properties of the consecutive heart beats. Applied to a number of dynamic phenomena, including HRV, fractal indices appear capable of detecting subtle changes in the dynamics of RR-intervals better than standard linear statistics. Spectral entropy and techniques based on "chaotic globals" attempt to overcome this disadvantage; avoiding limited data hazard [10, 11].

As mentioned above, the literature indicates the beneficial effects of musical auditory stimulation for a protracted time on HRV[2]. However, no previous study investigated the short-term effects of music on global chaotic parameters of HRV. The knowledge of physiological responses induced by music exposure is important to development of future therapies to prevent the development of cardiovascular disorders. Thus, we endeavored to investigate the acute effects of a selected baroque musical auditory stimulation on the globally chaotic parameters of HRV.

Material and methods

Study population. The subjects were 27 healthy male students — all non-smokers, aged between 18 and 22 years old. All volunteers were informed about the procedures and the 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 (CEP-2011-385), and were in accordance with Resolution 196/96 National Health 10/10/1996.

Exclusion criteria included body mass index (BMI) >35 kg/m^2; systolic blood pressure (SBP) >140 mmHg or diastolic blood pressure (DBP) >90 mmHg (at rest); cardiac arrhythmias (atrial flutter or fibrillation, multiple ventricular or atrial ectopy, second or third degree atrioventricular block); smoking; left ventricular dysfunction; reported neurological or respiratory disorders; and relevant auditory disorders.

Initial Evaluation. Baseline information collected 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. BMI was calculated as weight/height^2, with weight in kilograms and height in meters.

Measurement of the auditory stimulation. Measurements of the equivalent sound levels were conducted in a sound-proof room using a SV 102 audiodosimeter (Svantek, Poland). The device was programmed to take measurements in the "A" weighting circuit with a slow response.

The measurement was made during the 10-minute session of relaxing classical baroque music. An insert-type microphone (MIRE — Microphone In Real Ear) was placed inside the auditory canal of the subject, just below the speaker, which was connected to a personal stereo. Before each measurement, the microphone was calibrated with an acoustic CR: 514 model calibrator (Cirrus Research plc).

For the analysis, we used Leq (A), which is defined as the equivalent sound pressure level and which corresponds to the constant sound level in the same time interval. It contains the same total energy as the sound. We also analyzed the frequency spectrum of the sound stimulation (octave band). The music ranged from 63-84 dB.

HRV analysis. The RR-intervals recorded by the portable 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 (RR-interval) file in "txt" format. Following digital filtering complemented with manual filtering for the elimination of premature ectopic beats and artefacts, 500 RR-intervals were used for the data analysis. Only series with sinus rhythm greater than 95% were included in the study.

Protocol. Data collection was carried out in the same soundproof room for all volunteers; the temperature was between 21° C and 25° C and the relative humidity was between 50 and 60%. Volunteers were instructed not to drink alcohol or caffeine for 24 hours before the evaluation. Data were collected on an individual basis, always between 6 and 9 pm to standardize the protocol. All procedures necessary for the data collection were explained to each subject separately, and the subjects were instructed to remain at rest and avoid talking during the collection.

HRV was analysed in the following periods: control protocol — the 10-minutes period before the exposure to musical auditory stimulation and the 10-minutes period during the exposure to musical auditory stimulation: (Pachelbel: Canon in D, 63-84 dB).

Chaotic Assessment. *Chaotic Global Parameters.* Since the time-series are very short we must apply power spectra to the data. Applying such algorithms converge faster than computed on inter-peak temporal separations. Precision is increased for any fine detailed structure when we use Welch method for spectral entropy [11] or spectral detrended fluctuation analysis (sDFA). The spectral multi-taper method (sMTM) applies the multi-taper spectrum. In sections 2.6.2 to 2.6.4, we summarize the chaotic global parameters. For detailed treatment, please refer to Garner and Ling [10].

Spectral Entropy. Spectral entropy is a function of the irregularity of amplitude and frequency of the power spectrums peaks. It is derived by applying Shannon entropy [11] to power spectra. Here, we calculate the power spectrum by Welch's method [10]. We set the parameters for the Welch power spectrum to: sampling frequency of 2Hz, zero overlap, a Hamming window with FFT length of 256, and no detrending.

This output is then normalized so that the sum of the magnitude is equal to unity; giving a normalized power spectrum. We then calculate an intermediate parameter which is the median Shannon entropy of the value obtained from three different power spectra using the Welch power spectra under three test conditions: a perfect sine wave, uniformly distributed random variables, and finally the experimental oscillating signal.

These values are then again normalized mathematically so that the sine wave gives a value of zero, uniformly random variables give unity, and the experimental signal between zero and unity. This final value corresponds to spectral entropy.

sDFA. DFA can be applied where statistics such as mean, variance and autocorrelation fluctuate with time. The difference with the sDFA algorithm is that the DFA is applied to the frequency rather than time on the horizontal axis. If the scaling exponent, α in DFA is not constant for the duration of time for the dataset; such variability can introduce further errors even over short time periods (10-15 minutes). This reduces when power spectra are analyzed by DFA algorithm, but phase information is lost. To obtain sDFA we calculate the spectral adaptation in exactly the same way as for spectral entropy using a Welch power spectrum with the same settings; but DFA rather than Shannon entropy is the algorithm applied.

sMTM. sMTM is founded on the elevated intensity of broadband noise in power spectra generated by irregular and chaotic signals. Multi-taper method (MTM), provides an approximation of both line components and the continuous background of the spectrum. MTM exploits the property that these adaptive orthogonally shaped windowed power spectra are extremely accurate.

These optimal tapers belong to a family of spectral functions termed discrete prolate spheroidal sequences (DPSS). MTM spectral estimation reduces spectral leakage and other inaccuracies compared to the single windowed non-adaptive techniques. sMTM is the area between the MTM power spectrum and the baseline. We set the parameters for MTM at: sampling frequency of 1Hz, time bandwidth for the DPSS is set to 3, FFT length of 256, and Thomson's adaptive nonlinear combination method to combine individual spectral estimates.

Chaotic Forward Parameter. The parameter [CFP*x* 1-7] is referred to as Chaotic Forward Parameter for the functions 1 to 7 below where it is applied to control and musical auditory stimulation datasets. Since sDFA responds to chaos in the opposite way of the others we subtract its value from unity when applying here. All three chaotic global values have equal weighting. [CFP*x* 1-7] are defined in the standard way as in Souza [12] and Vanderlei [13].

$$1[CFP_x]=\left[\left(\left[\frac{sEntropy}{\max(sEntropy)}\right]\right)^2+\left(\left[\frac{sMTM}{\max(sMTM)}\right]\right)^2+\left(1-\left[\frac{sDFA}{\max(sDFA)}\right]\right)^2\right]^{\frac{1}{2}}$$

$$2[CFP_x]=\left[\left(\left[\frac{sEntropy}{\max(sEntropy)}\right]\right)^2+\left(1-\left[\frac{sDFA}{\max(sDFA)}\right]\right)^2\right]^{\frac{1}{2}}$$

$$3[CFP_x]=\left[\left(\left[\frac{sEntropy}{\max(sEntropy)}\right]\right)^2+\left(\left[\frac{sMTM}{\max(sMTM)}\right]\right)^2\right]^{\frac{1}{2}}$$

$$4[CFP_x]=\left[\left(\left[\frac{sMTM}{\max(sMTM)}\right]\right)^2+\left(1-\left[\frac{sDFA}{\max(sDFA)}\right]\right)^2\right]^{\frac{1}{2}}$$

$$5[CFP_x]=\left[\left(1-\left[\frac{sDFA}{\max(sDFA)}\right]\right)^2\right]^{\frac{1}{2}}$$

$$6[CFP_x]=\left[\left(\left[\frac{sMTM}{\max(sMTM)}\right]\right)^2\right]^{\frac{1}{2}}$$

$$7[CFP_x]=\left[\left(\left[\frac{sEntropy}{\max(sEntropy)}\right]\right)^2\right]^{\frac{1}{2}}$$

Results

Statistical analysis. Parametric statistics generally assume the data are normally distributed, hence the use of the mean as a measure of central tendency. If we cannot normalize the data we should not compare means. To test our assumptions of normality we apply the Anderson-Darling and Ryan-Joiner tests. The Anderson-Darling test for normality applies an empirical cumulative distribution function, whereas the Ryan-Joiner test is a correlation based test. The results from both tests show equal number of non-normal and normal distributions so we decided we must apply both the Kruskal-Wallis test of significance, non-parametric; in addition to the one-way analysis of variance (ANOVA1) [14]; a parametric test (Tab. 1).

The most significant combinations of chaotic globals are CFP 1 and CFP3. CFP1 is expected to be the case as it was so in the previous studies by Souza, et al. [12] and Vanderlei, et al. [13]. Nevertheless, CFP3 with the sDFA parameter absent is more significant. In both cases the Kruskal-Wallis test outperforms the ANOVA1 function. Other than CFP1 and CFP3, all values were $p>0,5$ which implies no statistical significance.

Principal component analysis. The multivariate technique principal component analysis (PCA) [14] can be applied here (Tab. 2). We have the values of CFP for seven groups in 27 subjects who underwent auditory stimulation; hence a grid of 7 by 27 to be assessed. The First Principal Component has a variance (eigenvalue) of 4,5282 and accounts for 64,7% of the total variance. The Second Principal Component has an eigenvalue of 2,4631 accounting for 99,9% of total variance. Therefore we can assume that most variance is acheived in the first two components. Thus, a reasonably steep scree plot.

When we observe the results of PCA; and recalling the ANOVA1 & Kruskal-Wallis statistical analysis we only

Table 1

The table shows the mean values and standard deviation of the Chaos Forward Parameters (1-7) for the normal and musically stimulated subjects RR intervals. The number of RR intervals is 500. Kruskal-Wallis and ANOVA1 tests of significance are applied to results giving a p-value

[CFP]	Mean Control (n=27)	Standard Deviation Control	Mean Music (n=27)	Standard Deviation Music	ANOVA1 (p-value)	Kruskal-Wallis (p-value)
CFP 1	0,9074	0,1139	0,8841	0,1137	0,4551	0,2035
CFP 2	0,6286	0,1302	0,6105	0,1083	0,5809	0,7819
CFP 3	0,8301	0,1042	0,8009	0,0984	0,2949	0,1095
CFP 4	0,7177	0,2175	0,7151	0,2085	0,9646	0,9655
CFP 5	0,3300	0,1687	0,3463	0,1556	0,7136	0,7819
CFP 6	0,6307	0,1661	0,6209	0,1596	0,8258	0,8086
CFP 7	0,4697	0,2381	0,4440	0,2128	0,6783	0,7687

Table 2

The table shows the Principal Component Analysis for CFP for seven groups for 27 subjects underwent musical auditory stimulation, PC1 represents the First Principal Component, PC2 the Second; until the seventh component PC7

Variable	PC1	PC2	PC3	PC4	PC5	PC6	PC7
CFP1	**0,228**	**-0,557**	**0,366**	**0,604**	**-0,097**	**0,189**	**-0,305**
CFP2	-0,302	-0,488	0,492	-0,506	-0,122	-0,394	0,049
CFP3	**0,012**	**-0,636**	**-0,550**	**-0,207**	**0,053**	**0,381**	**0,320**
CFP4	0,465	-0,089	0,038	0,232	0,313	-0,522	0,592
CFP5	0,468	0,052	0,334	-0,444	0,548	0,375	-0,166
CFP6	0,460	-0,130	-0,414	-0,218	-0,173	-0,445	-0,570
CFP7	-0,458	-0,140	-0,192	0,191	0,738	-0,230	-0,316

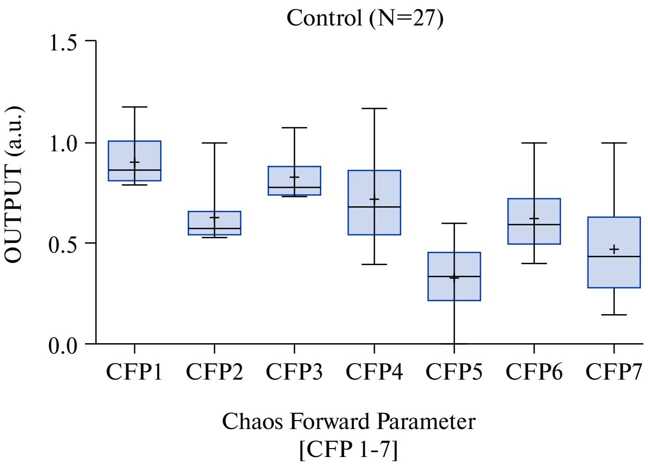

Figure 1. The box plot illustrates the mean values and standard deviation of CFP for control subjects ECG RR intervals. The mean value is indicated by the (+) symbol in the box plot. There are 500 RR intervals across 27 subjects.

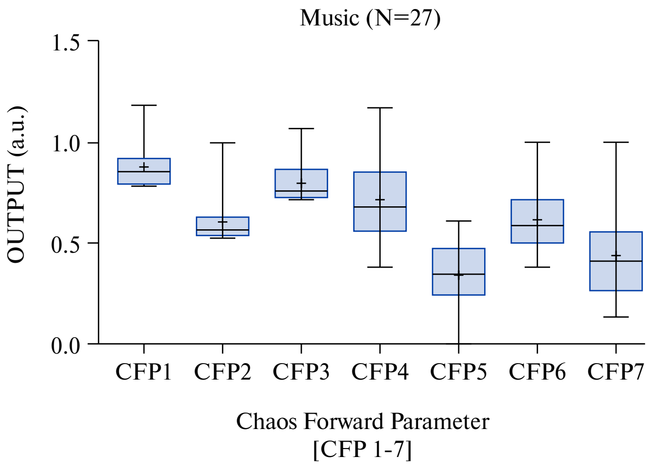

Figure 2. The box plot illustrates the mean values and standard deviation of CFP for the ECGs RR intervals of subjects with musical auditory stimulation. Mean values are indicated by the (+) symbol. All 27 subjects have data of length 500 RR intervals.

observe CFP1 and CFP3. CFP3 is very weakly influencial with first principal component (PC1) at 0,012; whereas, CFP1 is much more influencial with PC1 of 0,2288. In addition to this information the second principal component (PC2) is approximately equal for CFP1 and CFP3 (-0,6 for each). Hence, when comparing statistical significance and multivariate analysis together, CFP1 is the most favorable algorithm, which applies all three chaotic global techniques to HRV. This was expected (Fig. 1 and 2).

Discussion

Considering that Bernardi, et al. [15] reported that specific musical phrases, commonly at a rhythm of six cycles per minute, can regulate cardiovascular control by reducing or increasing sympathetic activity — whereas others indicated contradictory data on cardiac autonomic responses elicited by music. This study was undertaken to investigate the acute effects of a selected baroque musical auditory stimulation on the global chaotic parameters of HRV. Significant differences between control measurements whilst at rest with no music exposure and exposure to music were not observed.

Although we expected significant cardiac autonomic responses induced by music, we found no significant difference between control and music exposure. In contrast, a different style of relaxant music was reported to chronically increase the parasympathetic modulation of the heart [2]. The authors observed that music therapy during eight months with popular Taiwanese songs with moderate, pleasant rhythms and tempos improved HRV of the patients treated with an anti-neoplasic cardiotoxic drug. The therapy proposed by the authors also involved learning how to play musical instruments and featured different instruments in each session. Moreover, Nakamura and colleagues [16] evaluated the effects of a classic relaxant music ("Träumerei" from Kinderszenen Op.15-7, R. Schumann) on the parasympathetic nerve activity of urethane-anesthetized rats and observed increased responses to this song style. The music applied in our study is not entirely relaxant, "Canon in D" from Pachelbel presents some pieces with high and low equivalent sound pressure. We believe that the style of music here was a methodological factor that may explain the absence of significant change.

The equivalent sound level of musical auditory stimulation is an important point to be raised. Noise intensity has been indicated to influence the effect of auditory stimulation on cardiac autonomic regulation [17]. The cardiac autonomic responses induced by auditory stimulation are conducted through some mechanisms, including the startle reflex, a response mediated by a brainstem circuit. It is a familiar effect based on an abrupt response of the heart rate and blood pressure to a sudden loud auditory stimulation. The common intensity used to induce a startle reflex is 110 dB, and this intensity is much louder than environmental noise. Nevertheless, subjects repeatedly exposed to between 60 dB and 110 dB white-noise stimuli were seen to become habituated over time with regard to their cardiac response [1, 2, 16].

In our study we investigated only men in order to avoid sex-dependent effects on cardiac autonomic regulation during exposure to musical auditory stimulation. Studies regarding differences between men and women concerning emotional involvement presented conflicting findings [18]. One investigation reported that women were more stress reactive compared with men in response to musical auditory stimulation. Alternatively, another study observed that sex-based differences in psychophysiological responses to music were strongly influenced by sexual hormones. After extensively reviewing the Medline database we noted that it lacks in the literature studies investigating differences between men and women in relation to the cardiac autonomic responses to music. It is suggested that the length of the time-series be doubled to 1000 RR intervals. This was the case for previous studies by Souza, et al. [12] and Vanderlei, et al. [13]. Only half this recommended length of data was practiced here. This is suggested as the main reason for poor levels of significance by ANOVA and Kruskal-Wallis tests.

Now, when calculating chaotic globals the phase information is lost. Further study could include standard non-linear measures of time-series such as DFA [9], Shannon entropy, approximate entropy [17] and possibly correlation dimension [19] be applied in addition to spectral entropy and sDFA. sMTM would be omitted as it is generally more appropriate to "inverse problems" and optimization.

Conclusion

Musical auditory stimulation with a specific classic style did not acutely influence the global chaotic parameters of HRV in a small sample of healthy male volunteers.

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