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The effects of musical auditory stimulation on heart rate autonomic responses to driving: A prospective randomized case-control pilot study

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ABSTRACT

Stress induced by driving has been revealed to increase the chances of cardiovascular complications and is involved or related to traffic accidents. In order to develop strategies to avoid health problems during driving we aimed to evaluate the acute effects of auditory stimulation with music on heart rate variability (HRV) during driving in congested urban traffic. This is a prospective cross-sectional randomized controlled pilot study conducted with five healthy women. Subjects were evaluated on two different random days, whose order of execution was established through a randomization process. In the music protocol the volunteers were exposed to music for the entire 20 min of traffic while in the control protocol the subjects performed the same procedures but were not exposed to any music. We noted that all Higuchi fractal dimension parameters except *Kmax* 10, *Kmax* 130 and *Kmax* 140 were reduced between pre-driving in the control protocol vs. driving in the control protocol. The same changes were noted between pre-driving in the music protocol vs. driving in the control protocol. In conclusion, musical auditory stimulation improved nonlinear HRV changes induced by driving.

1. Introduction

Driving through congested urban traffic is a normal part of modern daily life.[1] Increased arousal while driving is not necessarily a negative state, since low levels of physiological stress are necessary for cognitive performance.[2] Then again, drivers frequently experience stressful situations that induce stress, including negative interactions with other drivers and urban traffic congestion.[3] It has been recognized in an elegant review that long term driving causes significant stress.[4]

Driving for two hours was capable of inducing physiological changes in subjects with cardiac impairment.[5] The authors evaluated catecholamine and 11-OHCS (cortisol) urinary excretion in 19 subjects with coronary artery disease and 17 healthy control subjects. The key results indicated that driving causes significant increases in the stated variables, demonstrating physiological stress and increase in the likelihood of cardiac problems.[6] Furthermore, stress during driving was similarly involved or associated with traffic accidents.[7] Taken together, reduction of stress during driving is vital to avoid medical and cardiac complications.

In this manner, heart rate (HR) variability (HRV) is a physiological phenomenon that corresponds to the fluctuations in the intervals between consecutive heart beats (RR interval & RRi) and provides physiological clarification concerning the autonomic nervous system.[8] HRV is explicitly influenced by stress and is able to detect stressful physiological responses.[9] Santana et al[10] suggested that HRV is more sensitive to recognize physiological stress compared to salivary cortisol levels. An important feature of HRV during stressful conditions is the possibility of ultra-short-term analysis (˜ 60 s), which identify subtle changes in HR autonomic control compared to regular short-term analysis (˜ 5 min).

Cardiac disorders are frequently treated with pharmacological agents.[11] Otherwise, auditory stimulation with music is a non-pharmacological balancing intervention that has received attention to reduce cardiac stress. Corbijn van Willenswaard et al.[12] performed a systematic review and meta-analysis so as to authenticate the influence of music on stress and anxiety in pregnancy. The review considered five studies eligible for inclusion. Amongst the methods applied, the references included the Antepartum Bedrest Emotional Impact Inventory,

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Perceived Stress Scale and State-Trait Anxiety Inventory. The authors specified the methodological quality as weak to moderate perhaps because of the lack of comprehensive physiological measurements.[12]

Constructive effects of music therapy with associated therapies were revealed in post-traumatic stress disorder.[13] Adult refugees treated in a clinic of traumatized refugees (psychic trauma related to persecution, torture, war, and so on) were submitted to a particular music therapy method based on variation of guided imagery and music and their symptoms improved. The authors investigated the impact of specific music programs while in an altered state of consciousness and simultaneous dialogue with a trained guide. The above-mentioned study reported that a specific form of receptive music therapy was a beneficial tool for post-traumatic stress disorder treatment.

In this way, it is worth highlighting that the simple act of listening to music is not music therapy.[14] Music therapy is a psycho-social intervention undertaken by a trained therapist.[15] In contrast, our research group intends to investigate music as a variable present in our daily routine. Also, a recent review revealed that music has a beneficial impact on the cardio-pulmonary system in the neonatal intensive care unit infants.[16]

The influence of music on HR autonomic regulation was assessed by Vanderlei et al. In this study healthy women were exposed to baroque classical and heavy-metal music. It was discovered there was a significant effect of heavy metal music, which decreased parasympathetic HR control, while no significant influence of Canon in D by Johann Pachelbel on HRV was achieved. The authors reinforced that the excitatory style of heavy metal music induced lessening in HRV. Conversely, this study did not elucidate whether classical music elicited significant relaxant effects.[17]

Additionally, contemporary music was able to improve the effects of anti-hypertensive medication on HRV in well-controlled hypertensive subjects.[18] This study stated that music styles written by Adele, Electra, Chris Tomlin and Enya positively influenced HR autonomic responses induced by anti-hypertensive medication.

In this way, driving is one of the most common music listening situations.[19] Persons listen to music in order to feel better or more involved when driving is solitary.[20] Considering that music is able to reduce stressful conditions,[10] we expected that music would attenuate HR autonomic stress during driving. Still, Brodsky[21] observed that fast-paced music negatively influenced the frequency of traffic violations, including lane crossings, disregarded red traffic lights and vehicular collisions, whereas slow-paced music did not. Interestingly, Ünal et al.[22] reported that higher levels of arousal during self-selected music listening improved drivers' response times to accelerations and decelerations of a lead vehicle while driving and proposed that music may provide beneficial stimulation when performing monotonous driving tasks.

Although the acute impact of music on stress during driving is not wholly elucidated, we emphasize the need of further studies to develop non-pharmacological interventions to reduce stress during this condition. Also, reduction of stress during driving is expected to decrease the likelihood of car accidents[7] and cardiovascular complications in subjects with cardiopulmonary disorders.[6]

Bearing in mind the above considerations, we raise the following questions: How much arousal or stress is excessive for driving? Is there an optimal level of arousal that one should aim for while driving? According to a recent study, slight reduction in HRV induced by physiological stress was able to impair auditory attention.[2]. These authors anticipated that RMSSD (root-mean square of differences between adjacent normal RR intervals in a time interval) values < 30 ms are capable of negatively influencing auditory attention. With this in mind, we expect that RMSSD < 30 ms during driving affect driving performance. So, we planned to assess the acute effects of auditory stimulation with contemporary music on HR autonomic control during driving under intense urban traffic conditions. We were concerned in testing a specific music program applied in a previous study that provided positive effects on HRV in hypertensive subjects[18] and we expect that this specially-selected music program helped attain this level.

2. Method

2.1. STROBE guidelines

Our study conforms to the STROBE (STrengthening the Reporting of OBservational studies in Epidemiology) guidelines. Our investigation covers particulars of the study design, setting, participants, variables, data sources, measurement, description of potential sources of bias, quantitative variables description, and statistical methods.

2.2. Studied population

We evaluated five women (three right-handed). We measured all subjects as non-habitual drivers; they have been known to drive between four to eight times per month (one to two times per week) with one to seven years of experience. With the aim of circumventing possible car accidents we selected a small number of subjects due to recommendation from the Ethical Committee in Research. The subjects drove the same car with the intention of standardizing the experimental procedures.

We excluded women that stated cardiopulmonary, neurological, psychological illnesses, and other disorders that did not permit them to perform the protocols and pharmacological treatments that influenced cardiac autonomic regulation. We excluded women prescribed oral contraceptive medications and those between the 10^{th} and 15^{th} days and between the 20^{th} and 25^{th} days of the menstrual cycle to remove the effect of the luteal and follicular phase, respectively. This is since, a former study indicated that HRV is influenced by the luteal and follicular phases of the menstrual cycle.[23]

2.3. Ethical approval and informed consent

All experimental procedures were previously analyzed and approved by the Ethics Committee in Research of our Institution (Number 385/2011) and a statement explicitly stating that the methods were undertaken in accordance with the 466/2012 resolution of the National Health Council of 12/12/2012. Informed consent was reached from all participants that signed a confidential consent letter.

2.4. Study design and setting

This is a pilot, observational, prospective, analytical and cross-sectional study performed in the downtown of Marilia city, a medium size city in Sao Paulo State, Brazil, inhabited by 220,000 people.

2.5. Bias

The experimental protocols were undertaken between 17:30 and 18:30 (rush hour) to standardize the circadian influences and to locate intense urban traffic. Temperature was maintained between 20 °C and 26 °C and humidity between 40% and 60%. Prior to the experimental procedures, all volunteers were advised to abstain from caffeinated and alcoholic beverages, and strenuous exercise for at least 24 h before each testing session. They consumed a light meal at only two hours before the experiment.

With the purpose of characterizing the sample, reduce the erraticism of the variables, improving reproducibility and physiological interpretation we logged anthropometric variables, including mass (kg), height (m), waist (cm), abdominal (cm) and hip (cm) circumferences, waist-to-hip ratio and body mass index (BMI).

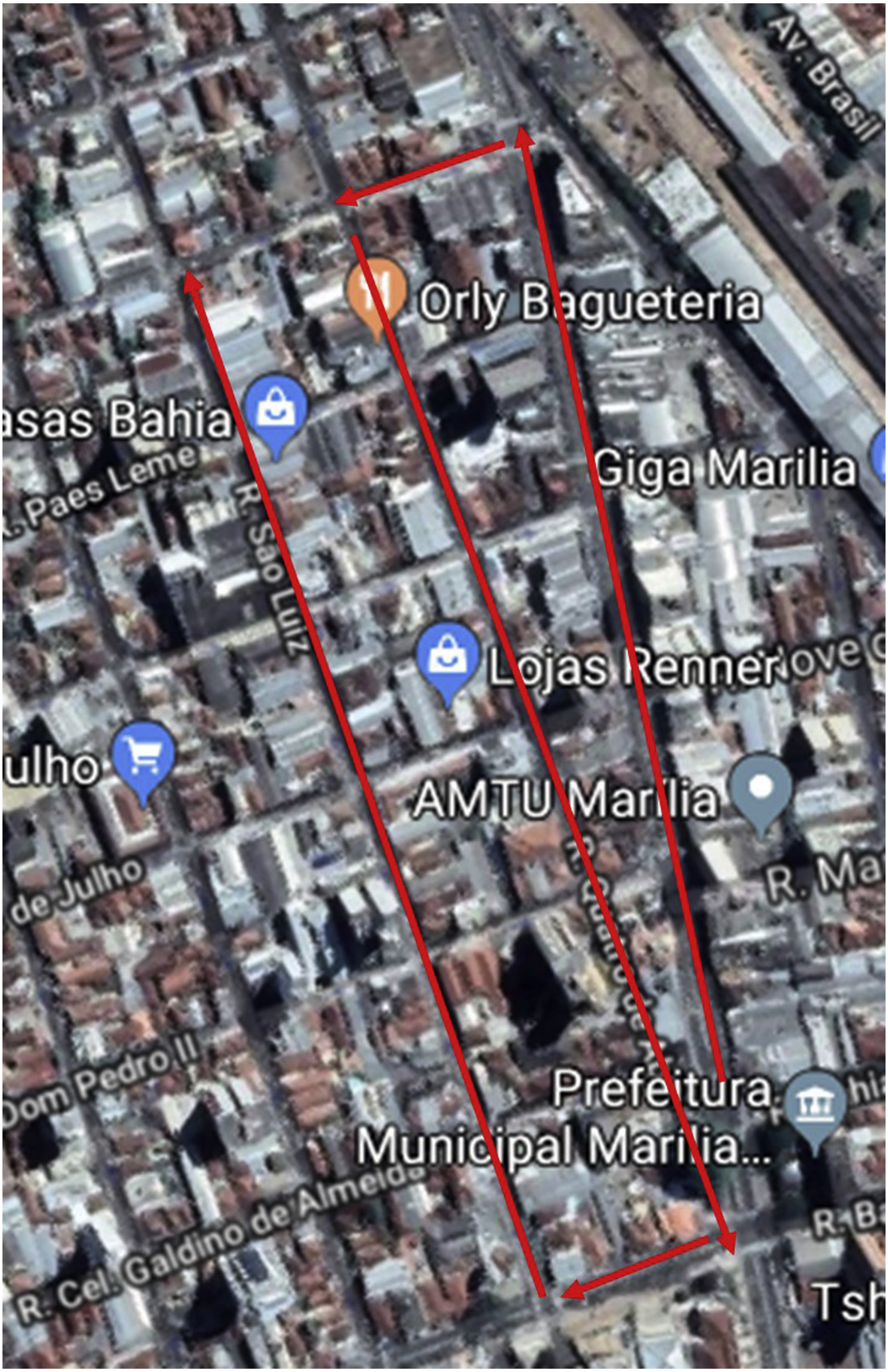

Fig. 1. Traffic route performed by the subjects.

2.6. Initial assessment and experimental protocols

At first, the subject remained seated in the car and the HR monitor was located on the volunteers' chest. Then, the experimental procedures were performed as follows:

1) Pre-drive: The subject remained seated at rest in silence under spontaneous breathing without sleep for 10 min in the car;
2) Driving under urban traffic congestion: The subjects drove for 20 min, the same route (3 km) (Fig. 1). The subjects remained in silence during the driving.

Subjects were evaluated in two different protocols with a minimum interval of 72 h between them. The order of enactment was established through a randomization process using a card (letter M indicates music protocol and letter C indicates control protocol). The card was selected by a subject unlinked to the study.

In the music protocol, the subjects were exposed to the subsequent music through a CD player in the car: 1-Someone like you (instrumental piano) – by Adele, 5 min 10 s; 2-Airstream – by Electra, 6 min 12 s; 3-Hello (instrumental piano), 4 min 20 s – by Adele; 4-Amazing grace [my chains are gone] [instrumental] by Chris Tomlin, 3 min 30 s and 5-Watermark by Enya, 38 s.[18] They were exposed to music during the entire 20 min of congested urban traffic. The subjects did not receive the music through an earphone since this is prohibited under the Brazilian traffic laws.

In the control protocol, the subjects performed the same procedures but were not exposed to music.

Nonlinear HRV analysis was performed in the final 10 min of HR recording based on 500 fixed stable RR intervals (RRi) while linear analysis was completed in the final 60 s based on 60 fixed stable RRi (Fig. 2).

2.7. Variables, data sources and outcome measures

2.7.1. HRV analysis

We applied the portable RS800CX heart rate (HR) monitor to record RR intervals with a sampling rate of 1 kHz. The RR intervals were transferred to the Polar Precision Performance program (v.3.0, Polar Electro, Finland). Preceding studies provide specific details of HRV analysis regarding filtering and artifacts elimination that we imposed.[24,25]

2.7.2. HRV linear analysis

Linear analysis of HRV included ultra-short-term RMSSD (root-mean square of differences between adjacent normal RR intervals in a time interval) in the time domain. We did not evaluate pNN50 since the Task Force[8] indicated that RMSSD provides more dependable information concerning the vagal HR control. SDNN was not evaluated because we intended to focus on an isolated parasympathetic regulation.

Ultra-short-term analysis considered the 60 RR intervals segments measures.[26] No effort was attempted to monitor respiratory rate since it was revealed that RMSSD remains consistent across paced or non-paced breathing patterns.[27,28] We applied the Kubios® HRV v. 2.0 software to compute these indices.[29]

2.7.3. HRV nonlinear analysis

To further investigate the effects of HRV during driving we performed nonlinear analysis via Higuchi fractal dimensions. Nonlinear methods provide complementary material related to traditional linear analysis. Whilst linear analysis of HRV evaluates the magnitude of the variability, nonlinear techniques assess the correlation properties, quality and scaling of the RR intervals.[30]

We completed nonlinear HRV through Higuchi fractal dimensions, which is based on fractal systems and exhibit a characteristic termed self-similarity.[31–33] The Higuchi fractal dimension is an algorithm that measures the fractal dimension of discrete time sequences.[34,35]

2.7.4. Statistical analysis

We performed a Shapiro-Wilk normality test to estimate the distributions. Comparisons of HRV indexes between protocols (driving vs. no driving) and moments were made by analysis of variance techniques to model repeated measures on a two factors scheme (two-way ANOVA) followed by Bonferroni post-test. Significant values were considered for $p < 0.05$.

3. Results

Table 1 displays mean and standard deviation of age, height, mass, body, body mass index, hip, abdominal and waist circumference and waist-hip ratio of the volunteers.

Linear analysis of HRV is illustrated in Table 2. According to two-way ANOVA, we found no significant difference between control and music protocols before and during driving regarding RMSSD.

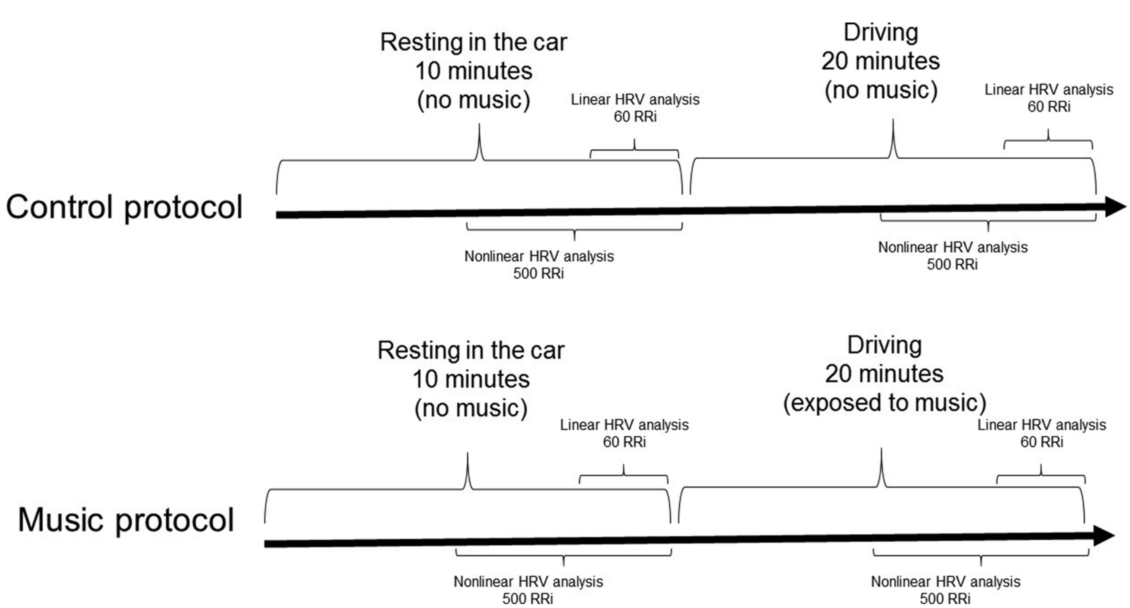

Fig. 2. Experimental protocols.

Table 1
Age, height, mass, body mass index (BMI), hip, abdominal and waist circumference and waist-hip ratio of the subjects.

Variables	Mean ± standard deviation
Age (years)	20.8 ± 1.40
Height (m)	1.64 ± 4.90
Mass (kg)	68.4 ± 8.90
BMI (kg/m²)	25.48 ± 3.60
Waist circumference (cm)	78.3 ± 5.70
Abdominal circumference (cm)	87.6 ± 6.30
Hip circumference (cm)	98.2 ± 3.70
Waist-hip ratio	0.79 ± 0.03

Mean ± standard-deviation; BMI: body mass index; SAP: systolic arterial pressure; DAP: diastolic arterial pressure; m: meters; kg: kilograms; cm: centimeters; mmHg: millimeters of mercury.

Table 2
Mean ± Standard Deviation (M ± SD) for the RMSSD index before and during driving in urban traffic in the control and music protocol. Mean ± Standard deviation; RMSSD: root-mean square of differences between adjacent normal RR intervals in a time interval.

Variable	No Music Pre-Driving	No Music Driving	Music Pre-Driving	Music Driving	p
RMSSD (ms)	40 ± 11.92	26.66 ± 5.40	54.34 ± 28.93	29.72 ± 17.70	0.07

Table 3
Mean ± Standard Deviation (M ± SD) for the Higuchi Fractal Dimension (HFD) statistics through *Kmax* between 10 and 150 at intervals of 10 for the subjects Pre-Driving with no music (n = 5) and subjects whilst Driving with no music (n = 5). Next, for the subjects with Music Pre-Driving (n = 5) and the subjects with Music whilst Driving (n = 5).

HFD K_{max}	No Music Pre-Driving	No Music Driving	Music Pre-Driving	Music Driving	p
10	1.71 ± 0.15	1.56 ± 0.08	1.74 ± 0.13	1.64 ± 0.06	0.1
20	1.81 ± 0.05 [a]	1.71 ± 0.05	1.83 ± 0.11 [a]	1.74 ± 0.05	0.02*
30	1.83 ± 0.03 [a]	1.76 ± 0.05	1.86 ± 0.10 [a]	1.78 ± 0.05	0.04*
40	1.86 ± 0.03 [a]	1.79 ± 0.05	1.88 ± 0.09 [a]	1.80 ± 0.04	0.03*
50	1.88 ± 0.02 [a]	1.81 ± 0.04	1.90 ± 0.08 [a]	1.81 ± 0.05	0.02*
60	1.88 ± 0.02 [a]	1.82 ± 0.04	1.91 ± 0.07 [a]	1.82 ± 0.05	0.04*
70	1.89 ± 0.02 [a]	1.83 ± 0.05	1.92 ± 0.06 [a]	1.83 ± 0.05	0.04*
80	1.90 ± 0.03 [a]	1.83 ± 0.04	1.93 ± 0.06 [a]	1.84 ± 0.04	0.03*
90	1.91 ± 0.03 [a]	1.84 ± 0.05	1.93 ± 0.06 [a]	1.84 ± 0.04	0.03*
100	1.91 ± 0.03 [a]	1.84 ± 0.05	1.93 ± 0.06 [a]	1.84 ± 0.04	0.03*
110	1.92 ± 0.03 [a]	1.85 ± 0.05	1.93 ± 0.05 [a]	1.84 ± 0.03	0.04*
120	1.92 ± 0.02 [a]	1.86 ± 0.05	1.94 ± 0.05 [a]	1.85 ± 0.03	0.04*
130	1.93 ± 0.03	1.87 ± 0.05	1.94 ± 0.05	1.85 ± 0.03	0.05
140	1.93 ± 0.01	1.87 ± 0.06	1.95 ± 0.04	1.86 ± 0.03	0.05
150	1.93 ± 0.01[a]	1.87 ± 0.06	1.95 ± 0.04 [a]	1.86 ± 0.04	0.04*

*Significance, two-way ANOVA test; Bonferroni Post-test: [a] Significance with protocol "No Music Driving".

Based on two-way ANOVA followed by Bonferroni Post-test, we noted that all Higuchi fractal dimension parameters except *Kmax* 10, *Kmax* 130 and *Kmax* 140 were reduced between pre-driving in the control protocol vs. driving in the control protocol. The same changes were noted between pre-driving in the music protocol vs. driving in the control protocol (Table 3).

4. Discussion

We attempted to investigate the conceivable impact of acute auditory stimulation with instrumental music on HRV responses induced by driving with the intention of authenticating whether music can relieve stress during intense traffic conditions. As key conclusion, we specify that musical auditory stimulation was able to lessen nonlinear HR autonomic changes elicited by driving.

We employed ultra-short term HRV through RMSSD index to identify subtle changes in HR autonomic regulation. Baek et al[36] reinforced the reliability of ultra-short-term HRV analysis, indicating this procedure as a consistent surrogate to measure trends in HRV. Also, ultra-short term HRV is able to provide more detailed information about HR autonomic changes, which short-term analysis are unable to achieve, since the parasympathetic influence on the heart dedicates under one minute.[37] However, we failed to find significant changes in RMSSD.

Based on our study, we reported significant changes in all Higuchi fractal dimension parameters, except *Kmax* 10, *Kmax* 130 and *Kmax* 140 during driving in the control protocol. These results support acute anxiety during this type of situation. When the identical subjects were exposed to music during driving, we found an absence of significant changes in HRV through RMSSD. This index represents evidence concerning the parasympathetic influence on the sinoatrial node.[38] Under stressful conditions the RMSSD index is reduced,[39] as observed in our cohort. Taken together, our findings suggest that auditory stimulation with instrumental music improved nonlinear HR regulation to urban driving.

In this context, nonlinear HRV methods differ from the linear techniques (time and frequency domain) because they do not evaluate solely the magnitude of variability. Nonlinear methods examine the scaling, quality and correlation properties of the signals. Nonlinear HRV analysis are related with the randomness, fractality and complexity of the signal.[40]

We decided to apply Higuchi fractal dimension because of several reasons: 1) it provides more detailed information concerning nonlinear HRV dynamics during physiological conditions, this is because this technique is able to analyze 500 RR intervals,[41] whereas other nonlinear indices request a minimal number of 1000 RR intervals[40]; 2) this method estimates the self-similarity and corresponds to the dimensional complexity of a time interval in the time series[31]; 3) increased values of Higuchi fractal dimension parameters are associated with increased parasympathetic activity[41] and 4) it was of late indicated to be more sensitive to detect physiological fluctuations.[41]

According to Higuchi fractal dimension analysis, we found that all parameters, except *Kmax* 10, *Kmax* 130 and *Kmax* 140 were significantly reduced during driving in the control protocol. Thus far, when the volunteers were exposed to music whilst driving, we found improved HRV; since there was significant reduction only in *Kmax* 120 to *Kmax* 150. This data reinforces the beneficial impact of music on stress induced by driving.

Previous studies support our statistics. The relaxant effects of music were formerly reported in different situations. It was recently revealed that music was able to improve HR autonomic regulation changes induced by antihypertensive medications in well-controlled patients.[18] Santana et al[10] investigated the influence of music on HRV during endodontic treatment. As expected HRV decreased during endodontic treatment, yet, in the group exposed to music HR autonomic control improved, therefore supporting the beneficial effects of music on stress during endodontic procedures.

In this manner, previous studies intended to explain the mechanisms involved in the interaction between music and autonomic nervous system. Recently, it was recommended that the frequency of the sound be disallowed as a major factor, since it was revealed that noises under specific frequencies did not cause substantial deviations in HRV.[42] The association between the hypothalamic-pituitary-adrenal axis and autonomic activity was emphasized as a positive impact of music on stress in lifestyle.[43] Under this condition, we anticipate that the psycho-physiological influence of music is one of the principal events related to autonomic deviations induced by the music.

Nakamura et al. [44] assessed the gastric vagal nerve activity and cardiovascular parameters in urethane-anesthetized rats when exposed to Traeumerei by Schumann and revealed that music increased parasympathetic activity. The same research group [45] logged renal sympathetic nerve activity in anesthetized rats during exposure to the identical music and observed that music reduced sympathetic activity and blood pressure. These responses were correlated to histaminergic neurons in the hypothalamic suprachiasmatic nucleus.

This pilot study offers pertinent data regarding the positive effects of music during driving. It is accepted that subjects with coronary artery disease present physiological stress reaction to driving task possibly due to autonomic influence,[5] increasing the possibility of sudden death or cardiovascular complications.[6] In this state, reducing the autonomic stress during driving is supportive for patients with cardiovascular disease who need to drive. Moreover, as previously stated, car accidents are related to increased stress.[7] So, we propose that music during driving may decrease the probability of car accidents.

Our study has some views that need highlighting. We performed ultra-short-term analysis so as to detect subtle changes in HRV, which are not identified by short term analysis. We evaluated only women with the intention of controlling the influence of sexual hormones, reduce the erraticism of the variables, improve reproducibility and physiological interpretation. Experimental studies indicate that auditory stimulation activates the mesolimbic reward pathway in females in a different way to those of males; in a similar reproductive condition.[46] Thus, auditory stimulation is suggested to provide more intense alterations in women. We did not apply questionnaires to avoid subjective influence of the volunteers in our results and for the reason that we aimed to focus only on physiological stress responses. We cannot promise that all participants were exposed to the same magnitude of experimental manipulation (namely, traffic). Yet, HRV analysis showed in the control protocol that traffic induced significant stress response.

Finally, although we evaluated only a small sample due to recommendations from the Ethical Committee in Research so as to avoid car accidents (and conceivable fatalities) because the volunteers were non-habitual drivers; statistical analysis exhibited significant decrease of HRV during driving in the absence of music.

5. Conclusion

Our pilot study anticipated that auditory stimulation with music improves nonlinear HRV changes induced by driving in urban traffic. We demonstrated that music may reduce cardiac autonomic overload and stress whilst driving.

Author contributions

Myrela Alene Alves collected data, performed conduction of experiments and draft the manuscript.

David M. Garner performed statistical analysis, draft the manuscript, extensively reviewed the manuscript, English Grammar and Spelling.

Joice A. T. do Amaral draft the manuscript, followed the journal guidelines and reviewed statistical analysis.

Fernando R. Oliveira remade statistical analysis and draft the manuscript.

Vitor E. Valenti supervised the study, draft the manuscript, wrote introduction and discussion section and gave final approval for the version submitted for publication.

All authors reviewed and approved the final version of the manuscript.

Declaration of Competing Interest

The authors declare absence financial and non-financial interests.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.ctim.2019.08.006.

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