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Music Listening and Heart Rate Variability

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Abstract

Listening to music is a complex phenomenon, involving psychological, emotional and physiological responses. Different mechanisms leading to music-evoked emotions have an effect on many physiological processes, such as regional heart activity, heart rate, heart rate variability (HRV), blood pressure and respiratory rate. HRV, variation in interbeat intervals, is a measure of autonomic nervous system (ANS) activity. Some HRV parameters can be used as an index of cardiac vagal tone. Our aim was to measure the effects of music listening on the modulation of ANS via the measurement of HRV. Thirty healthy adult volunteers, mostly students, aged between 21 and 40 years, were exposed to music listening via headphones in a supine position, between 7 a.m. and 14 p.m. HRV was analyzed from interbeat intervals recorded via ECG. Musical preferences, musical background and feelings of pleasantness or unpleasantness were documented with the use of questionnaires. Each person participated in three recording sessions, with distinct protocols: 1) preselected music comprised of four different genres (classical music, baroque music, Gregorian chants and ambiental music), 2) participant self-selected music and 3) silent control. The music chosen by the participants varied greatly compared to music chosen by the researchers in terms of tempo, genre and elicited arousal. Participants reported self-selected music to be more pleasant than the music chosen by the researchers. Listening to music showed a trend in decreasing activity of the parasympathetic (vagal) ANS function when compared to baseline conditions (resting HRV) or when compared to control (silence), although no statistically significant difference was found.

Introduction

Listening to music is accompanied by changes in neurological, psychological and physiological functions (Chanda & Levitin, 2015). Different mechanisms leading to music-evoked emotions have effects on regional heart activity, heart rate, heart rate variability (HRV), blood pressure and respiratory rate (Koelsch & Jäncke, 2015). Music yields a variety of different physiological effects and can act as a means of physiological excitation or relaxation. Music listening also modulates the function of the autonomic nervous system (ANS) by changing the relationship between sympathetic and parasympathetic system activity. A stress-reducing effect of inhibition of the sympathetic nervous system and activation of the parasympathetic nervous system has been considered as one of the beneficial effects of music, although the underlying mechanisms and dynamic changes in simpatico-vagal balance remains to be fully elucidated (Finn & Fancourt, 2018; Ooishi, Mukai, Watanabe, Kawato, & Kashino, 2017).

Some parameters of heart rate variability (HRV), determined from the variation in interbeat intervals, are commonly used measures of parasympathetic activity (index of cardiac vagal tone) and are correlated with the outcome of different clinically relevant conditions (García Martínez et al., 2017). HRV analysis is also often used in psychophysiological studies, the results of which are acknowledged to be connected with self-regulation at the cognitive, emotional, and social levels (Park, Vasey, Bavel, & Thayer, 2014). Although HRV is a simple method, it can be easily misinterpreted, as there are numerous factors influencing it (previous sporting activity, smoking, alcohol, coffee, body weight, age, gender, circadian rhythm, disease, medications, and others) (Laborde, Mosley, & Thayer, 2017).

Previous studies of physiological effects elicited by different music genres show that tempo affects the arousal, whereas major/minor mode affects mood (Husain, Thompson, & Schellenberg, 2002). Nevertheless, due to the application of very heterogeneous musical stimuli in different studies, there is inconsistency when the effects of specific musical stimuli on ANS are being determined along with corresponding cardiovascular changes and therefore its impact on clinical settings (Koelsch & Jäncke, 2015). Currently, there are no general guidelines for music listening in clinical settings, as the studies vary in musical protocols and findings. Our aim was to investigate the effects of music on the modulation of the ANS via the measurement of HRV. We evaluated the hypothesis that music listening is a simple non-pharmacological method that can be used to influence the listener's psychophysiological state.

Methods

Participants and Experimental Protocol

Thirty volunteers (8 males and 22 females) aged from 21 to 40 years, mostly students (83%), were exposed to music, which they listened to via headphones (Table 1).

Table 1. Basic characteristics of the participants.

	Mean [SD]
Age [years]	25 [4]
Body mass index [kg/m2]	22 [3]
Waist to hip ratio	0.81 [0.1]
Importance of music in participants' daily life on a 7-point Likert-type scale (7 = very important)	6.1 [0.9]

The subjects were asked not to take stimulants or consume large meals before the experiment, to sleep normally and not to exercise extensively on the day before the experiment. Before the experiment, a questionnaire was given to collect data on the amount of sleep and exercise they had the previous day, the consummation of food and stimulants (caffeine, cigarettes, alcohol) before the experiment, their medical status and their connection to music (Table 1). Participants were mostly healthy with four participants being overweight, two participants on antidepressives and one on antihistamine medication at the time of the experiment.

The questionnaire also included questions regarding musical background: musical education and frequency of engagement with music (active or passive listening) (Table 2). Half of the participants had a certain level of musical education (53%), half of the participants had none (40%) or were self-taught (7%).

Table 2. Engagement with music.

	Never	**Less than 4 times a month**	**1 time per week**	**Several times per week**	**Everyday**
Frequency of active engagement with music (playing an instrument, sing or compose) [%]	37	17	13	23	10
Frequency of actively choosing music for listening (at home or on the way) [%]	0	13	3	30	53

All the experiments were performed at the facilities of the Institute of pathological physiology of the Medical faculty in Ljubljana. Measurements were taken while participants were alone in a quiet room, lying in a supine position on an examination table, between 7 a.m. and 14 p.m., with an ambient room temperature of 21 to 23° C.

Each participant was recorded with three study protocols: 1) preselected musical pieces comprising of 4 different genres (one composition per genre, random order), 2) self-selected musical pieces by each participant and 3) control without music. The music listening protocol comprised of three parts, the first being a baseline recording (10 minutes of quiet rest), the second being intervention or reactivity phase (4 times of 5 minutes of music with a 30-second pause in between) and the third, a post-intervention recovery period (10 minutes of quiet rest). Before the session, participants listened to a short demo of the music they would be listening to during the protocol and were asked on how they felt about each of the presented musical pieces (level of pleasantness on a 7-point Likert-type scale) and if they are familiar with the musical piece (binary yes or no answer). The level of pleasantness for each piece was then recorded again immediately after the session. Sound levels were controlled for and were between 55 and 70 dB. The control protocol with quiet rest had the same overall length as the two musical protocols (41.5 minutes).

Three lead ECG (0.05 – 100 Hz, AHA) was continuously recorded with a data acquisition unit (Biopac M35), Ag-AgCl electrodes were placed on the participants' torso (AHA placement). Respiration rate was controlled for with a respiration belt transducer (Biopac Systems). The study was approved by the National Medical Ethics Committee of the Republic of Slovenia and all participants signed a consent form.

Music Set Self-selected by the Participants

Experimenters prepared a mix of each participant's favorite songs and artists, based on a list given by the participant. Each playlist contained four pieces, each piece was comprised of one 5-minute-long section of a song or out of two 2.5 minutes long sections of two songs with a soft passage in between. Tempo, genre, and elicited arousal were determined for each user-selected piece. The tempo was measured in beats per minute (BPM), genres were determined broadly (no subgenres were used) and elicited arousal for each piece was determined to be either "relaxing" or "exciting". Each playlist was therefore described with tempo range, general arousal (in cases where there were two pieces marked as exciting and two as relaxing, the category "ambivalent" was used) and the genres used.

Music Set Prepared by the Researchers`

For the experimentalists` playlist, we decided to use Bach's and Mozart's music, a Gregorian chant and an ambiental piece, genres that usually show the most beneficial effects on well-being (Campbell, 2009; Dryden & Vos, 2001; Habe, 2005). The inclusion criteria for the musical sections were as follows: less well-known musical pieces of 5 minutes in length, with a tempo of 60 to 85 BPM, they had to begin and end softly (not in the middle of a phrase) and without any surprising elements, overly repetitive and slow parts. We used the standard tuning of the recordings.

A Gregorian chant was used because of its repetitiveness, steadiness and predictability of the music (Almeida & Silva, 2012; Gatti, 2005). After consulting with a specialist, we chose a chant without instrumental accompaniment, with rather low pitched vocals, which carry a "bordun" voice (a constant underlying tone).

Bach's music was chosen due to its constant tempo, which gives the listener the feeling of flow (there are no sudden and sharp interruptions). It is believed that listening to baroque music may encourage the production of alpha waves in the brain, which is connected to feelings of relaxation and calmness (Dryden & Vos, 2001; Gu, Zhang, Zhou, & Mei, 2014). We created a list of fifteen different musical pieces, which all met the proposed criteria (all of them also being instrumental pieces) and after careful listening, J. S. Bach: Orchestral Suite No. 2, Ouverture was chosen.

W. A. Mozart's music was chosen mainly because of its balance regarding harmony, pitch range and melodical formation (Campel, 2009; Habe, 2005). Harmonical features are mainly very predictable and simple, the pitch is never extremely high or low and the melodical forms are gradual, without large jumps. The music keeps a fine balance between the excitation and relaxation of the listener. Going through

Mozart's music, we excluded most of the vocal repertoire, focusing on the instrumental pieces with an accurate tempo. Very few musical pieces maintained the right tempo and included the selected features for the desired period of time. The final choice was W. A. Mozart: Symphony No. 29, Andante.

Ambiental music was also chosen because of its steadiness and calmness. Natural sounds, such as bird chirps and the sound of water flowing were included, but in a combination with a steady pulse and instrumental accompaniment. The piece we chose is T. Kokubo: The Blue Planet Seen Far Away.

Heart Rate Variability

HRV is derived from interbeat intervals. ECG recordings were manually checked for artifacts and ectopic beats, which were excluded and RR intervals exported (BSL PRO 4.1). Selected time domain and frequency domain parameters were calculated based on 5-minute windows with package RHRV (García Martínez et al., 2017) in statistical programming language R:

- SDNN – standard deviation of all normal-to-normal interbeat intervals, the estimate of overall HRV
- RMSSD – root mean square of successive interbeat differences, representation of vagal tone
- pNN50 – the percentage of successive normal sinus RR intervals than 50 ms, representation of vagal tone
- HF – the power of high-frequency range (0.15 – 0.4 Hz), corresponds to respiratory sinus arrhythmia associated with vagal tone. HF was calculated with Welch`s periodogram and fast Fourier transform.

Statistical Analysis

Statistical analysis of the level of pleasantness was performed using statistical programming language R version 3.5.3 (R Core Team, 2017). Since data were not normally distributed (Shapiro-Wilk normality test: $P < 0.05$), data were analyzed with a nonparametric test (Pairwise Wilcoxon Rank Sum Test).

Statistical analysis of changes in HRV parameters during a time and between study groups was performed with SigmaPlot (Systat).

Results

Playlist Characteristics

The genres and subgenres used in the participants` self-selected playlists were very diverse. Genres were categorized into six groups and assigned to the individuals` playlists (percentage represents the number of times one form of the genre is represented in thirty individual playlists). There was no limitation on the number of genres represented in one playlist:

- Pop music (80%)
- Rock music (57%)
- Classical music (33%)
- Ethno music (10%)
- Electronic music (23%)
- Rap music (7%)

Participants` playlists also varied a great deal in terms of speed. We enlisted each playlist into one out of six selected groups with average tempo:

- Slow tempo, 30 – 70 BPM (10%)
- Slow – medium tempo, 50 – 90 BPM (20%)
- Medium tempo, 70 – 100 BPM (17%)
- Medium – fast tempo, 90 – 120 BPM (7%)
- Fast tempo, 100 – 140 BPM (10%)
- Diverse tempo (it enlists into more than one of the above-listed groups) (37%)

The elicited arousal of the participant`s playlist was categorized into three groups. Each playlist was enlisted into one of the three selected groups:

- Exciting (with at least 3 out of 4 pieces of playlist exciting) (43%)
- Relaxing (with at least 3 out of 4 pieces of playlist relaxing) (27%)
- Ambivalent (two pieces of playlist were exciting and two relaxing) (30%)

For comparison, the characteristics of preselected music were as follows:

- Genres: three pieces of classical music and one ambiental piece

- Tempo: slow – medium tempo, 50 – 90 BPM
- Arousal: ambiental (relaxing), classical pieces were on the verge between exciting and relaxing (neutral)

Participants Characteristics

Students with different levels of musical education were included and generally, the music presented an important role in the everyday life of these students (Table 1). All the participants recognized their self-selected music, which was mixed by the researchers. Approximately half of the participants recognized the preselected musical pieces by Bach (40%) and Mozart (50%), while only 5 people (17%) marked ambient musical pieces and Gregorian chants as familiar. The levels of pleasantness from the expectation before the session, until after the session remained the same for self-selected music, while the level of pleasantness increased after listening to preselected music (Figure 1). Nevertheless, the feeling of pleasantness after listening to preselected music remained lower than the feeling of pleasantness after listening to self-selected music (Figure 1).

The Effects of Music Listening on Heart Rate Variability

The results of the selected time and frequency domain parameters of HRV are presented in Figure 2. When comparing HRV during control study protocols to both intervention protocols, a decrease of HRV parameters indicative of vagal activity (RMSSD, pNN50 and HF) was noticed within the period of listening to either self-selected music or music chosen by the researchers. Although this downward trend persisted throughout the whole 20 minutes' intervention period, the differences between resting HRV and reactivity HRV parameters did not reach statistical significance for either the self-selected neither or preselected musical protocol. In addition, a comparison of HRV parameters between the three different research protocols also showed that lower reactivity of HRV during music listening was not statistically significant when compared to HRV parameters from control protocol, neither there was no statistically significant difference when we compared the two intervention groups with each other. Interestingly, pNN50, RMMSD and HF in the recovery phase, after music listening (last 10 minutes of musical protocols) was significantly increased when compared to HRV parameters during the reactivity period of music listening.

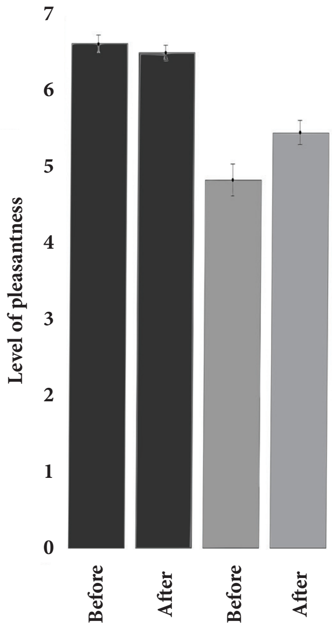

Figure 1. Level of pleasantness evaluated on a 7-point Likert-type scale. For each individual, the level of pleasantness was determined based on the average rating of all four musical pieces for each of the two musical protocols, before and after the session. Levels of pleasantness before and after the session were compared for self-selected (black) and preselected (grey) musical protocols. In addition, levels of pleasantness were compared between both musical protocols only after the session. Statistically significant difference was observed among all comparisons except for before and after listening to self-selected music (Pairwise Wilcoxon Rank Sum Test, *p* < .05).

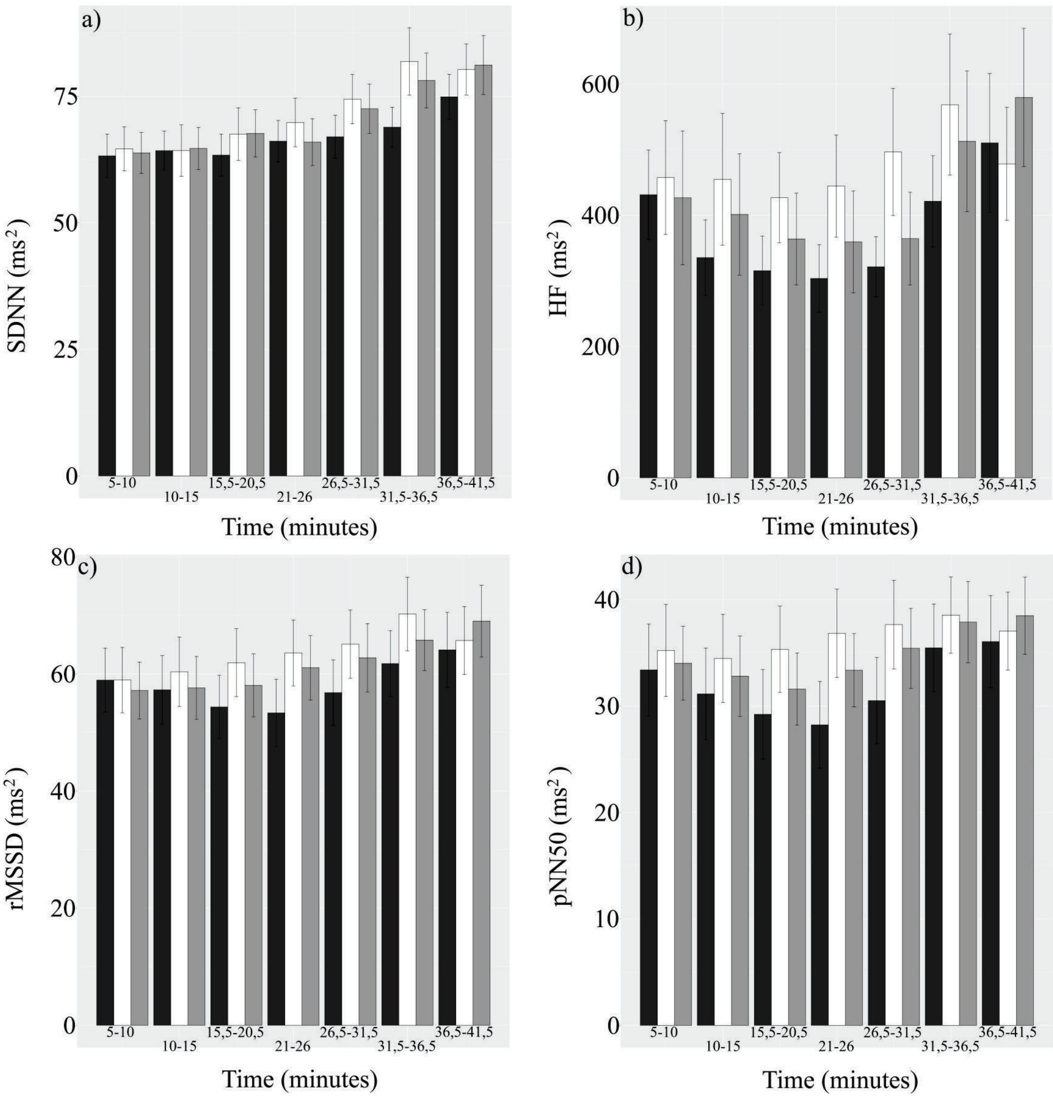

Figure 2. Results from different HRV parameters. Selected parameters were calculated from 5-minute windows. HRV was calculated from a 5-minute window before intervention (the first 5 min of the baseline recording part was excluded), during four 5-minute windows of stimulation with music and after the intervention from two 5-minutes windows. Time windows for analysis were the same for resting participants without stimulation. All HRV parameters show a similar trend of vagal tonus activation through the duration of the experiment (two way repeated measures ANOVA, *p* < 0.05). Black columns – self-selected music; Grey columns – preselected music; White columns – control with silence.

Discussion

The characteristics of the self-selected music chosen by the participants varied greatly, compared to researchers` chosen music in terms of tempo, genre and elicited arousal. The tempo of the participants` chosen music was diverse, varying from person to person and between musical pieces on a single playlist. The range of the tempo was between 30 and 140 BPM, a much greater range in comparison to the 60 to 80 BPM, used in the researchers` playlist. The range of the genres used was also much greater, many more genres and subgenres were included than in the researchers` playlist. The elicited arousal of the participants` playlist was in most cases exciting often ambivalent and in some cases relaxing. Compared to the researchers' music, of which elicited arousal was mainly neutral, or rather a little bit on the relaxing side of the spectrum, the participants` music was much more exciting. Participants chose varied music, only one musical piece was present in two playlists. Some listeners chose well-known artists and some chose publicly largely unknown artists. Thus the stimuli of an individual`s playlist were in the majority of cases very different from the stimuli of the playlist made by the researchers. Participants, mostly students, found self-selected music significantly more pleasant than the music chosen by the researchers. Nonetheless, the difference was only for one point on a 7-point Likert-type scale and the researchers` music was still perceived as pleasant.

The level of excitement was also reflected in the measurements of HRV parameters representing cardiac vagal tone during 20 minutes of music listening. Listening to music (self-selected or music chosen by the researcher) showed a trend in decreased activity of the parasympathetic (vagal) ANS function when compared to baseline conditions (resting HRV) or when compared to control (silence). Although we found no significant difference in HRV between the three different study protocols, or between baseline conditions and listening to music, we must be careful in drawing conclusions. Notably, the statistical power was low due to the large intra-individual differences in HRV and due to the small number of participants. The interesting finding of our study is a significant increase in HRV parameters, indicating higher parasympathetic (vagal) tonus in the recovery phase (after music listening), which is similar to the cardiac parasympathetic reactivation following physical exercise (Stanely, Peake, & Buchheit, 2013).

The results of the present study contribute insights into the effects of music listening on the autonomic modulation of cardiac function as indicated by HRV analysis. Well-designed experimental studies comparing the effects of one's own music with the effects of pre-selected classic music genres on the modulation of the ANS are sparse. Therefore, the critical discussion based on the results of other studies is limited (Lynar, Cvejic, Schubert, & Vollmer-Conna, 2017).

Conclusions

The music chosen by the participants varied greatly, compared to music chosen by the researchers in terms of tempo, genre and elicited arousal. Participants evaluated both musical protocols (self-selected music and music chosen by the researchers) as enjoyable. The pleasantness of self-selected music on a 7-point Likert-type scale was rated significantly higher. Listening to music showed a trend in decreasing activity of the parasympathetic function when compared to baseline conditions or when compared to control. However, the trend was not significant. This is probably due to the great intra-individual differences and a bigger sample of participants is needed. Notably, HRV parameters, indicating higher parasympathetic (vagal) tonus in the recovery phase after music listening, increased significantly when compared to the reactivity phase during music listening. Music listening has future perspectives as a simple non-pharmacological method to modulate the listener's ANS function in a clinical setting.

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