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Article

Exploring Interactions between Physiological Mechanisms and Music Riffs: Power beyond Music

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Abstract: This study aims to discuss whether the baroreflex is regulated by the music with 0.1 Hz oscillations and determine which musical component most elicits the baroreflex control. We had the subjects listen to the music with 0.1 Hz oscillation (in either chords or rhythm) and the same music without 0.1 Hz oscillation. The power of the extracted components up to 0.1 Hz significantly increased blood pressure (BP) at $p < 0.05$regardless of which music they listened to. However, the coherence between BP and heart rate fluctuations up to 0.1 Hz increased significantly ($p < 0.01$) only when listening to the music with continuous riffs up to 0.1 Hz. The results implied that properly applied repetitive riffs of music improve the baroreflex regulation.

Keywords: Music therapy, Blood pressure, Heart rate, Cardiovascular synchronization

1. Introduction

Listening to music evokes various neurophysiological responses along with alterations in cardiovascular and respiratory regulations [1−3]. Music has been incorporated into treatment for alleviating clinical symptoms such as stress, anxiety, and even neuropsychiatric symptoms [2]. However, the response to music is personal and depends on the individual's preferences. Multiple factors in music intertwine with personal neurophysiological responses, making it difficult to standardize or unify the usage of music treatment [2]. There are several fundamental elements in common even in the different types of music such as tempo, rhythm, and the changes in volume. According to previous research, the physical properties of music sound waves arouses specific physiological mechanisms. The increasing sound volume (crescendo or emphasis) elicits progressive skin vasoconstriction, along with an increase in blood pressure (BP) and heart rate (HR). This response is related to sympathetic activation regardless of individual neurophysiological response [3]. In addition, similar physiological responses of BP and HR are observed when listening to a fast and low complexity rhythm of the drum loop [4]. Although the related studies revealed easy ways to alter the regulation of physiological systems irrespective of the types of music, how to combine the fundamental elements to tailor a clinically useful music therapy is still poorly understood. For example, the baroreflex sensitivity, a crucial control mechanism of BP, decreases while listening to the drum loop with fast and low complexity rhythm but remains unchanged while listening to the music with slow crescendo and decrescendo rhythm. A study has shown that the entrainment of BP and HR oscillation at the natural frequency of Mayer's wave (a prominent fluctuation of BP oscillate at 0.1 Hz) increases the baroreflex sensitivity and lowers BP by triggering the resonant frequency of both systems via 6 cycle-per-minute respiration [5]. The rhythmic change of the sound volume in the several sceneries of the opera "Va, pensiero" coinciding with 0.1 Hz resonant frequency increased Mayer wave's amplitude [3] and potentially modulate baroreflex control. This study, therefore, aims to discuss whether the baroreflex control is enhanced by the music embedded with 0.1 Hz oscillations and determine which musical component entrains the baroreflex control the most.

2. Materials and Methods

2.1. Study Procedure

The experimental procedure was approved by the local ethics committee (LSHIRB No.:17-035-B1). We recruited 12 healthy young subjects (7 males and 5 females) ranging the age from 20 to 35 years old without hypertension or cardiovascular disease. After signing the consent form, the subject stayed in a silent room and wore circumaural headphones to listen to music. At the same time, the physiological monitor was recording the releveant data of the full experiment without interruption. The beat-to-beat heart rate (HR) and continuous blood pressure (BP) were recorded by a Nutronic noninvasive blood pressure measurement system (BMEYE Nexfin). After a 5-minute baseline, the three sessions were played in turn, and the duration of music of each session was 162 s. Between each session, there was a 5-minute resting period to remove the possible effects of music.

2.2. Music Types

Three sessions of music with different grooving levels were composed to investigate whether the groove enhances the Mayer waves and elicits the baroreflex control. The basic groove was created with riffs, that is, repeating phrases. Using riffs as an accompaniment is a common way to arrange the tune. In the composition, one riff was composed with four bars, lasting 10 s. Thus, the periodicity of the riffs loop was similar to Mayer waves. During each session, the subjects listened to one of three different combinations of musical arrangements: (1) the musical theme with grooving riffs, where the theme weakened the grooving of music, (2) the same musical theme without groove, maintaining the same chord with the riffs but with less complexity in rhythm, and (3) only grooving phrases without the main theme.

2.3. Data Analysis

We separated the experiment into four parts: (1) baseline, (2) the musical theme with grooving riffs, (3) the same musical theme without groove, and (4) only grooving phrases without the main theme. The spectrogram was constructed using continuous wavelet transform (CWT) to observe the dynamical changes of the oscillation of Mayer waves and explore the discernment of the spectrogram during different situations. The amplitude of the Mayer waves (the oscillation of BP up to 0.1 Hz) was quantified by the summation of the power between 0.075−0.125 Hz of the spectrum calculated by fast Fourier transform (FFT) (Fig. 1). The BP raw data were randomly permutated 100 times to obtain the distribution of the power spectrum density of noise. The power lower than 95% confidence level was regarded as noise and was discarded.

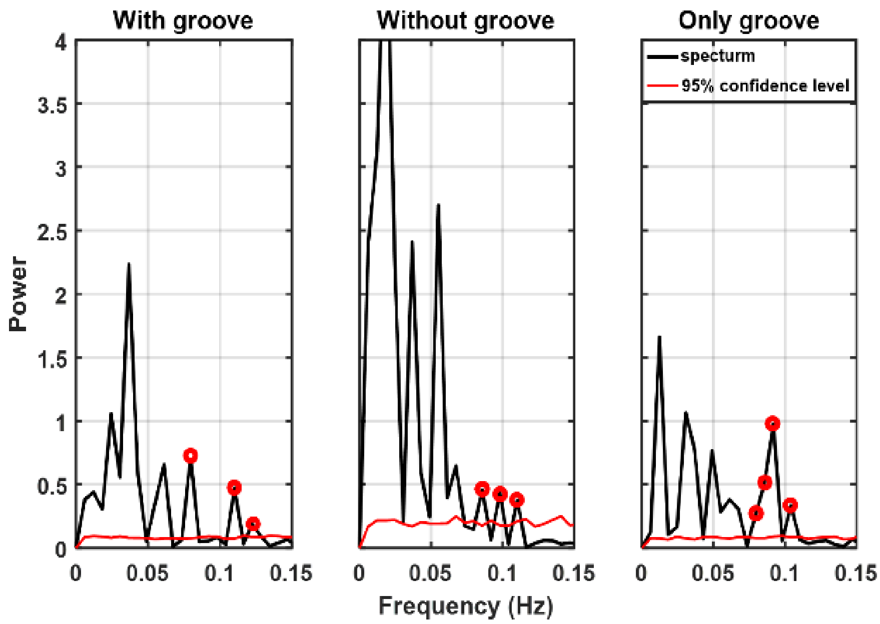

Fig. 1. FFT power spectrum. The red points which are greater than 95% confidence level were acceptable to calculate.

To understand the correlation between BP and HR, the coherence between BP and HR was calculated from the CWT spectrogram, which represents the level of synchronization. Continuous Wavelet Transform is believed as a reliable and robust method to access cardiovascular dynamics of the ANS due to its adaptability and adjustability between spectral and temporal scales using a window of variable width. Its flexible temporal-spectral resolution, unlike short-time Fourier transform (STFT), allows CWT to provide more information about the complex functioning of autonomic regulatory mechanisms. CWT was used for the time-frequency map. The continuous Morlet wavelet function is shown as

$$\Psi_0\left({}^{t}/_{s}\right) = \pi^{-1/4} e^{j\omega_0 t/s} e^{-1/2(t/s)^2}, \quad (1)$$

where t and s are time and scale, respectively. Then, the convolution of the analyzed function $g(t)$ with a scaled wavelet function is defined as CWT,

$$\mathrm{W}(\mathrm{s},\tau) = \int g(t)\Psi_s(t-\tau)dt \tag{2}$$

The relationship between the temporal and spectral aspect of the Morlet wavelet is shown below

$$\lambda = \frac{1}{\mathrm{f}} = \frac{4\pi s}{\omega_0 + \sqrt{2+\omega_0^2}} \tag{3}$$

where λ is the Fourier wavelength analyzing dynamic cardiovascular signals in the time-frequency or time-scale domain. There are two types of coherence: frequency function of coherence by using CWT amplitude and frequency function of coherence by using CWT phase[6,7]. The frequency function of coherence by using CWT amplitude is defined as

$$K_{xy}(s) = \frac{\sqrt{\langle W_{xy}(s)\rangle}}{\sqrt{\langle W_{xx}(s)\rangle}\sqrt{\langle W_{yy}(s)\rangle}} = \frac{\left|\sum_{l=1}^{N} W_{x_l}^{*} W_{y_l}^{*}\right|}{\sqrt{\sum_{k=1}^{N} W_{x_k}^{2}}\sqrt{\sum_{m=1}^{N} W_{y_m}^{2}}} \tag{4}$$

where W_{xx} and W_{yy} are the wavelet spectral density function and W_{xy} is the cross-wavelet spectrum. Similar to the Fourier-based coherence, the value of wavelet coherence varied between 0 and 1.

Furthermore, the frequency function of coherence by using the CWT phase is defined as

$$P_{xy}(s) = \left|\frac{1}{N}\sum_{k=1}^{N} e^{j\left(\theta_x(s,k)-\theta_y(s,k)\right)}\right|, \tag{5}$$

$$\theta_x(s,k) = phase\{W_x(s,k)\}, \tag{6}$$

$$\theta_y(s,k) = phase\{W_y(s,k)\} \tag{7}$$

The phase coherence was used to compute the contribution of phase synchronization. However, the magnitude-squared coherence computes the contribution of both phase and amplitude synchronization [8]. To represent the coherence level of up to 0.1 Hz, we averaged the coherence values between 0.075 to 0.125 Hz (Fig. 2).

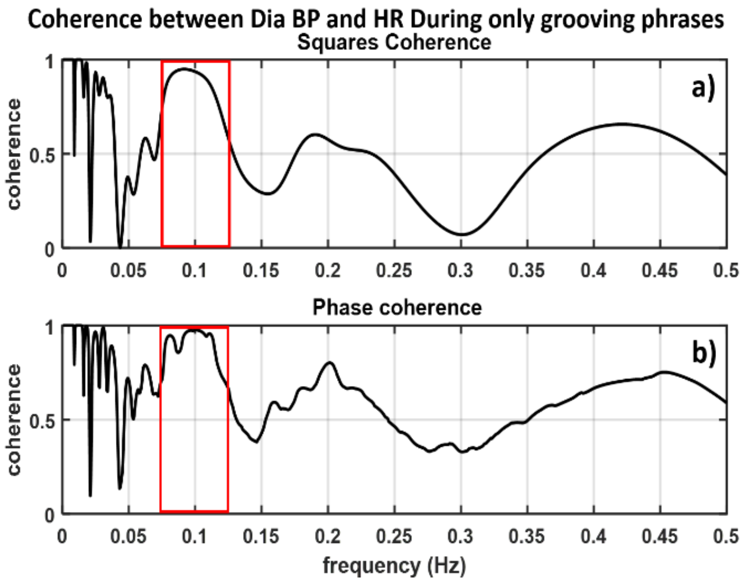

Fig. 2. Coherence values in difference frequencies. (**a**) the squared coherence, (**b**) the phase coherence: the averages of 0.075-0.125 Hz coherence represented the synchronization level.

2.4. Statistical Analysis

There are six distinct response variables: (1) up to 0.1 Hz power in systolic BP, (2) up to 0.1 Hz power in diastolic BP, (3) the average of squared coherence up to 0.1 Hz between systolic BP and HR, (4) the average of squared coherence up to 0.1 Hz between diastolic BP and HR, (5) the average of phase coherence up to 0.1Hz between Sys BP and HR, and (6) the average of phase coherence up to 0.1 Hz between diastolic BP and HR. The continuous variables were represented as mean values±SD. The differences between each music session and baseline were tested by repeated-measures analysis of variance with the Tukey HSD test. A p-value less than 0.05 was considered statistically significant. All statistics were calculated using the open source statistical program R (version 2.15.2).

3. Results

In the CWT spectrogram, the power of up to 0.1 Hz in BP increased gradually when subjects were listening to a pure grooving melody (Fig. 3(b)). At the same time, the synchronization of BP and HR was more distinct (Fig. 3(d)). However, this phenomenon was not observed in other music sessions or baseline. Compared to the baseline, the power of up to 0.1 Hz components extracted from systolic or diastolic BP significantly increased regardless of the music they listened to ($p < 0.05$). That suggested that the amplitude of Mayer waves in BP was enhanced by music stimulus. The result in coherence was similar to the quantified 0.1 Hz power in BP. It demonstrated that Mayer waves were correlated with HR changing and echoed previous research [9]. Both the squared coherence and the phase coherence between systolic or diastolic BP and heart rate fluctuations up to 0.1 Hz increased significantly only when listening to the music with continuous riffs at up to 0.1 Hz ($p < 0.01$), which indicates the enhanced baroreflex control of the cardiovascular system.

Fig. 3 illustrates a typical spectrogram of diastolic blood pressure (DBP) and dynamics of DBP and HR after 0.02−0.15 Hz band pass filtering during baseline and music with the only loop. When compared to baseline, the power of BP increased gradually following the grooving. At the same time, the synchronization between BP and HR was more obvious. All the quantified values displayed in Table 1 and the statistical analysis are shown in Table 2. The level of grooving corresponds to the level of phase coherence. The results implied that properly applied repetitive riffs of music improve the baroreflex regulation. In the second and third sessions of music stimulus (the musical theme with grooving riffs and only grooving phrases without the main theme), we did not obtain significant results in all response variables when compared to the baseline or each other. This result suggested that only pure grooving enhanced the baroreflex.

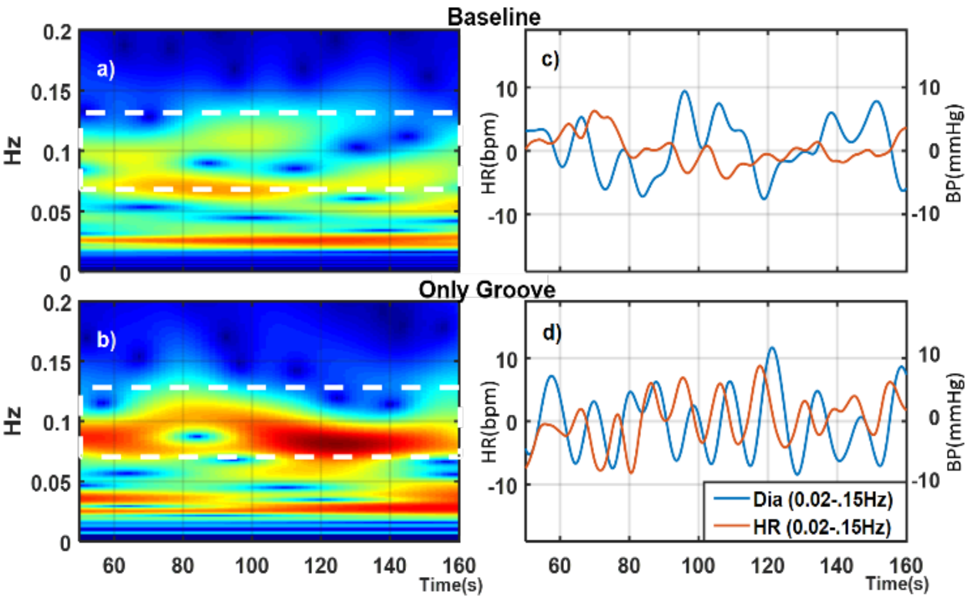

Fig. 3. Time-frequency spectrogram of diastolic blood pressure (DBP). The power of DBP up to 0.1Hz was enhanced during loop music (**b**). compared with baseline (**a**), dynamics of DBP and HR up to 0.1Hz are shown in (**c**) and (**d**). The synchronization of DBP and HR is more prominent during loop music (d) compared to baseline (c).

Table 1. Six Response Variables of Systolic and Diastolic blood pressure during four Situation.

	Baseline	Groove with Theme	Without Groove	Only Groove
Power of BP_{sys}	0.12±0.09	0.18±0.18	0.24±0.32	0.49±0.58
Power of BP_{dia}	0.08±0.05	0.16±0.11	0.18±0.15	0.29±0.23*
Systolic squared coherence	0.59±0.16	0.67±0.14	0.66±0.18	0.77±0.13*
Diastolic squared coherence	0.57±0.15	0.69±0.13	0.69±0.16	0.78±0.12*
Systolic phase coherence	0.68±0.13	0.76±0.09	0.70±0.14	0.82±0.09*
Diastolic phase coherence	0.68±0.14	0.78±0.08	0.75±0.11	0.82±0.09*

The value was expressed as Mean±std; * $p < 0.05$ vs. baseline.

Table 2. Anova with tukey posthoc test table.

	Anova P	2-1	3-1	4-1	3-2	4-2	4-3
Power of BP_{sys}	0.06	0.98	0.83	0.06	0.97	0.14	0.31
Power of BP_{dia}	0.02	0.64	0.37	0.01	0.97	0.16	0.35
Systolic squared coherence	0.04	0.58	0.68	0.03	1.00	0.35	0.27
Diastolic squared coherence	0.01	0.22	0.20	<0.01	1.00	0.31	0.33
Systolic phase coherence	0.02	0.31	0.98	0.02	0.53	0.58	0.05
Diastolic phase coherence	0.03	0.13	0.43	0.02	0.90	0.84	0.43

4. Discussions and Conclusions

Music is frequently used in therapeutic settings, specifically for mental health diseases to induce comfort and relaxation, as well as to minimize or regulate discomfort. Slow music, for example, has been proven to lower blood pressure and respiration rate. In addition, although the effect of music differs from person to person, it has been proven to increase sleep quality and manage anxiety. Burrai *et al.* [10] looked into the beneficial effects of listening to classical music with the standard care in improving several factors including sleep quality, anxiety, quality of life, and cognitive stage of home-cared patients with heart failure. The results showed that listening to classical music reduced both anxiety and depression in patients that simultaneously improved their quality of life. Moreover, researchers have delved into observing if music stimulated cardiovascular signals in expanding the therapeutic potential of music. Bernardi *et al.* [3] examined the cardiovascular responses to musical compositions characterized by variable emphasis and whether they were reflected in the music profiles. They found that music synchronized the change in cardiovascular and respiratory signals. In addition, van Dyck *et al.* [11] confirmed that when people listened to music, a significant increase in heart rate was observed, when compared to silence. These results demonstrate that during passive music listening, music influences a general arousal effect on heart rate.

To find an objective physical property of music to enhance baroreflex control, we composed music with 0.1 Hz riffs, since the riffs can be easily embedded into any type of music without changing the main theme of the music. The riffs are repeated phrases that add grooving to the music. The riffs were repeated every 10 s, thus one of the frequency components in music matched the resonant frequency of the Mayer wave. The study result found that music listening caused stimulation as it changed BP and HR in response to music in different situations. Previous studies focused on only two situations (silent and music or slow and fast music), rather than four situations as this study (silence, the musical theme with grooving riffs, the same musical theme without groove, and only grooving phrases without the main theme). All three situations increased both HR and BP specifically with the 0.1 Hz oscillation. Furthermore, the situation where only grooving was listened to produced the highest increase in both BP and HR. The main melody dampened the increase a little compared to pure groove only. The grooving created by musical riffs increased Mayer waves in BP according to the result of this study. In addition, even short-term (162 s) exposure to grooving music brought out a significant result compared with baseline. We assume that the length of duration is not a key point. The result implied that properly applied repetitive riffs of music improved the baroreflex regulation. From the results in this study, we concluded that music, regardless of the type, certainly stimulated the baroreflex control.

Author Contributions: M.-T.L. and C.L. have conceptualized the study and developed the protocol. Z.-W.C. helped to obtain data and analyze the data. B.M.F.C., Z.-W.C. and C.L. drafted the manuscript. C.L. have helped to interperte the results and participated in the final review of the manuscript. All authors contributed to the article and approved the submitted version.

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Conflicts of Interest: The authors declare no conflict of interest.

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