Paper

Investigation of synchronization between musical beat and heartbeat with cardio-music synchrogram

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Abstract: To illuminate the synchronization phenomena between heartbeat and music, the effects of a sedative music of variable tempo on heart rates were investigated. In the experiment, nine subjects were exposed to the sedative music with having changes in its tempo. The tempo gradually increases, decreases, or stands stable in the music (hereafter these experimental condition are named as Up, Down, and Flat condition). With regard to the analysis of synchronization, we introduced our formerly developed Cardio-Music Synchrogram, which was used to extract statistically significant synchronization period between heartbeat and music. As a result, it was suggested that the sedative music in Down condition induced synchronization more frequently than Flat and Up conditions.

Key Words: synchronization, musical beat, heartbeat, Cardio-Music Synchrogram

1. Introduction

Music is one of the most popular forms of media and gives us positive effects on our body and mind. It is well known that the relaxation music moderates patients anxiety and even alleviates their physical pain. Music has long history in psychophysiological research (e.g., [1, 2]), however the effects of music on our body and mind have not yet been totally elucidated. Music consists of variety of components;

tone, tempo, melody, harmony, instruments, etc. These components can be one of the reasons for the difficulties faced in psychophysiological research on music. Meanwhile a previous study investigating the effectiveness of these components suggested that the tempo of music exerted stronger influence on listeners impression of the music [3].

How does musical tempo affect listeners? Bason et al. have made the first step for the answer for this question by investigating the relationship between sound and heartbeat [4]. They have successfully observed an entrainment of heartbeat intervals with pure tones having a particular tempo. Inspired by this finding, a series of attempts have been made to investigate the entrainment and/or synchronization of heartbeat with music [5-11]. Among those the definition and measure of synchronization were also discussed. Kusunoki et al. have recently developed Cardio-Music Synchrogram (CMS), which is a useful tool to visualize the synchronization between heartbeat and music. They have also proposed a methodology to extract the synchronization periods with CMS by introducing statistical criteria [9]. Introducing the idea of CMS, Fukumoto et al. have demonstrated the synchronization between heartbeat and relaxation music of variable tempo gradually slower [10]. These studies confirmed the phenomena of the synchronization; however, it was still hardly adequate because of their experimental limitations. Since the previous studies mainly focused on the methodology of Cardio-Music Synchrogram (CMS), the experimental condition were limited, thus a sedative music with decreasing tempo was alone assessed. Therefore, from the technical point of view, it is not clearly discriminated whether the changes in tempo elicited an entrainment effect or the “sedative” music merely induced the reduction of heart rate, and as a result, “synchronization” was virtually observed. To clarify this point, we design the experiment with distinct conditions in tempo, Down, Flat, and Up, as described in the next section we investigate the phenomena of synchronization by means of introducing CMS.

2. Method

2.1 Subject

Nine subjects participate in the listening experiment. All subjects did not have any special experience with music and had no diseases with the heart or any hearing impairments.

2.2 Experimental procedure

In the experiment, a sedative music, Gymnopedy No.1 composed by E. Satie, which consists of three tempo variation was prepared as the music stimuli: 1) the tempo was on increasing (hereafter it is named as Up condition), 2) the tempo was on decreasing (Down), and 3) the tempo was stable (Flat). Each experimental trial consisted of 4 minutes of initialized period, 10 minutes of music stimuli (Up, Down, or Flat), and 1 minute of rest. The initial tempo of the music was set to 66 beats per minute (bpm) for each tempo condition. Then it was constantly increased (decreased) 2 bpm/min in Up (Down) conditions, thus it ended up to 86 bpm (46 bpm) at the end of 10 minutes music exposure. These music stimuli were prepared using Musical Instrument Digital Interface (MIDI), and played by software (Sonar, Roland) via external sound source module (MU500, Yamaha). Prior to the experiment, each of the subjects set the sound volume to an adequate level of their preference to minimize a negative effect of such a possible confound factor.

Including no music exposure as for the control condition, all subjects individually went through these four experimental trials (Up, Down, Flat, and no music) consecutively with 10 minutes interval between each trial. To avoid an order effect, the order of the four trials was counter-balanced as far as possible.

After the experimental trials the heart rate of the subjects (instantaneous heart rate, more precisely) was determined by applying a threshold method to the electrocardiogram (ECG) data collected by 1000Hz of sampling rate. The synchronization period between heartbeat and the music stimuli was analyzed by the idea of CMS described in the next section.

2.3 Cardio-music synchrogram (CMS) and the determination of the synchronization period

CMS was developed by Kusunoki et al. (2003) for visualizing the synchronization between music and heartbeat [9]. Figure 1 shows the schema on how to construct the CMS. In CMS the horizontal and vertical axes represent time and musical beat, respectively. Musical beat develops along with time. Especially in Flat Condition, musical beat linearly develops along with the time development as shown with the bold line in Figure 1. Then at the moment of heartbeats are plotted on the line. This plotted heartbeat corresponds to the phase of musical beat. Also that plotted image is folded according to a particular musical beat unit (modulo) so that one can easily grasp the chaining in heartbeat-music phase correspondence in the time series. If the synchronization occurred, apparent parallel lines of the heartbeat plots emerge in CMS. According to previous studies [9, 10], the modulo consisted of three, four, and five musical beats were introduced to illustrate the variety of ratios of the synchronization.

Based on the idea CMS, the synchronization periods were determined by the statistical analysis proposed by Kusunoki et al. [9]. In brief, the distribution of the heartbeat plots within a certain period is statistically compared with that of random distribution. Then if it were sufficiently rare at pre-defined significant level, $p < 0.01$ in this study, the corresponding period is extracted as for the synchronization period. Further description can be found in [9].

3. Results

3.1 Synchronization periods in cardio-music synchrogram

Figure 2 shows a profile of the change in the heart rate of a subject in Down condition. The change in the tempo is also depicted as a linear solid line in this figure. Since the heart rate fluctuated largely as shown in this figure, it is quite difficult to extract the synchronization period between heartbeat and music.

On the other hand, Figure 3 shows the CMS constructed by the same data set as used in Figure 2. These CMSs are found by three, four, and five modulo, respectively. The synchronization periods are denoted as the black band above each CMS. Several synchronization periods were observed in each CMS with the synchronization ratios of 1:1 (around 60 s and 100 s), 5:6 (around 330 s), 4:5 (around 420 s and 480 s), and 3:4 (around 540 s). Such a variety of synchronization periods were observed for all subjects in all three conditions.

Fig. 1. Construction of Cardio-Music Synchrogram for observing the synchronization between heartbeat and musical beat.

Fig. 2. Examples of change in heart rate of a subject and development of musical tempo in Down condition.

Fig. 3. Examples of CMSs and extracted synchronization periods in Down condition.

3.2 Length of the synchronization periods

The total length of the synchronization periods of CMSs of three, four, and five modulo for each subject were found for the purpose of comparison among the three experimental conditions. For example, the total length of the synchronization periods of the data set shown in Figure 2 was 199.3 seconds. It should be noted that the synchronization periods overlapped each other in CMSs of three, four, and five modulo are corrected as the total length for the reasonable comparison.

Figure 4 shows the average and standard deviation of the total length of the synchronization periods of Up, Down, and Flat conditions. As a result of the multiple comparison by *t-test* with *Bonferroni correction*, at the significance level of ($p < 0.05$), the length of the synchronization period in Down condition is significantly larger than Flat condition.

3.3 Change in the heart rate

Figure 5 shows the difference in the heart rate between the averaged heart rate of during 1 minute before and after the musical stimuli: in which standard deviations are omitted because they are too large. As a result of the multiple comparison, there was no significant difference among them.

The average heart rate at the initial period was 68.6 bpm. However, with its large deviation

($SD = 12.3$), there was no significant correlation between the heart rate and the total length of the synchronization periods of each subject, irrespective of the conditions.

4. Discussion

The novel findings of this study were the experimental proven facts of that a sedative music in Down condition induced synchronization more frequently than Flat and Up conditions; while the synchronization was still be observed in Flat and Up conditions. As already mentioned, the sedative music is well known to alleviate the activities of a variety of physiological functions including automatic nervous system and cardiovascular system. Thus it can be assumed that some sort of synergetic effect between entrainment of the heartbeat with tempo and such physiological effects induced by a sedative property of a music resulted in relatively longer period of synchronization during Down condition. This assumption can be ascertained in a future work investigating whether uplifting music had stronger synchronization effect in “Up” condition than Flat and Down.

During the synchronization period the heart rate should change along with the changing in musical tempo, e.g. the heart rate would decrease during the synchronization period in Down condition as it was formally reported by Nagashima et al. (2004) [11]. However, as shown in Figure 5, there was no significant difference in the heart rate before and after the musical exposure. Therefore, the synchronization would not keep going continuously in the time series but would emerge discontinuously.

Fig. 4. Average and standard deviation of total length of the synchronization periods between all subjects.

Fig. 5. Average of increase of heart rate between subjects.

It implies that the homeostatic property [12] of the heart beat regulation might compensate or even overcome the driving force of the synchronization.

The possible mechanism of the synchronization phenomena is still a matter in discussion. The entrainment of the respiration by the music [13] and the synchronization between the respiration and heartbeat has previously been reported [14]. It implies the possibility of the respiration as the mediator of synchronization between music and heartbeat. Pikovsky et al. (2001) described the synchronization as an “adjustment of rhythms of oscillating object due to their weak interaction” [15]. Thus, one can easily imagine that a music having a particular tempo would initiate some sort of physiological effect on heart beat regulation system; that would form such a “weak interaction”. Meanwhile, other previous studies have reported that velocity of music affects change in listeners’ cardiovascular activities [16, 17]. Further accumulation of the experimental facts needs to discuss the physiological dynamics or neurological pathway involved in the synchronization.

5. Conclusion

In this study, the synchronization between heartbeat and a sedative music was investigated with variable musical tempo. Introducing CMS and statistical analysis for the synchronization period, the longer synchronization period was observed when the tempo of the sedative music gradually turned slower; whereas there was no significant change in the heart rate between before and after the music exposure.

Further study might lead to the idea of manipulation of heartbeat by music. In the ergonomic point of view, it has huge potential in the context of music therapy, stress management, ambient interface, etc.

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