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Investigation of Synchronization between Tempo of Sound and Heartbeat with Cardio-Music Synchrogram

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Abstract– In this study, to investigate fundamental properties of the synchronization between heartbeat and musical beat, three musical stimuli having different change of tempo were employed in the listening experiment. Changes of tempi were Up, Flat, Down. Cardio-Music Synchrogram that is a kind of statistical method was applied to observe and investigate the synchronization. In comparison of the length of synchronization period, significant effect of musical tempo on the length was observed. Furthermore, shortest synchronization period was observed in Flat condition. Although there was the difference of the length between the conditions, change of the heart rate between before and after the listening musical stimuli was not observed. Synchronization, i.e. phase locking was considered as not successive phenomenon.

1. Introduction

Music is well known as one of the popular media and is often used for making atmosphere in shop, changing mood in personal use, etc. Relaxation effect of music is used for reducing anxiety of patient, and some previous researches have partly revealed the psycho-physiological effect through the experiment.

Musical piece is constructed from many factors. To verify main effective factor of music, a previous study has compared the effectiveness of musical factors and clarified that tempo is the most effective factor on listener's impression [1]. Effect of tempo is generally realized as relating to listener's impression: fast tempo affords excitation, and slow tempo affords relaxation.

How does musical tempo affect on listeners? Observing tempo and physiological index of listener from non-linear point of view may clarify the mechanism of the effects of music. As a first trial, Bason et al. have investigated the relationship between sound and listener's heartbeat [2]. They have observed an entrainment of heartbeat intervals by interval of consecutive pure tones. Based on this finding, previous studies have investigated the entrainment and synchronization of heartbeat by musical tempo [3-9]. Kusunoki et al. have developed Cardio-Music Synchrogram (CMS), which is effective tool to visualize the synchronization between heartbeat and musical beat [7]. Fukumoto et al. have investigated the synchronization between heartbeat and beat of relaxation musical piece which changes its tempo [8]. However, concrete properties of the synchronization are not clarified yet.

In this study, the synchronization between heartbeat and musical beat is investigated. Same musical pieces with three kinds of change of tempo were used in the listening experiment. CMS is used for observing the synchronization, and length of detected synchronization periods is compared. To investigate the difference of effect of the three musical stimuli, change of heart rate is compared. From engineering point of view, the entrainment and synchronization of heartbeat intervals by musical tempo would be used for several applications in the area of entertainment, therapy, media contents, etc.

2. Method

2.1. Procedure

2.1.1. Subject

Seven subjects participate in the listening experiment. All subjects don't have special training of music.

2.1.2 Experimental Method

The listening experiments are performed in a quiet room. All subjects participated in four experimental conditions. Each condition is constructed from three parts; 4 min rest, 10 min listening, and 1 min rest. In 10 min listening part, subjects listen to four different stimuli through headphone including three musical stimuli and

no-music. To avoid the order effect, the order of four stimuli is randomized.

As physiological index, electrocardiogram is measured during each of the listening experiments. Times of R-waves in the electrocardiogram are detected as times of heartbeats. To compare the effect of four stimuli, heart rates (number of heartbeats per 1 min) between before and after the listening part are compared. Furthermore, to observe the synchronization between musical beat and heartbeat, CMS is constructed afterward of the all listening experiments. The length of synchronization periods is compared between three musical conditions.

2.1.3 Musical stimuli

All of three musical stimuli are made from same musical piece, and Gymnopedy No.1 composed by E. Satie is selected as the musical piece. Tempi of them are initially set 66 beats per minute (bpm), but two of them change its tempo. The musical piece and initial tempo of three musical stimuli are defined by referring to the previous study [8]. Three musical stimuli and their tempi are described as below.

Down condition: 66 bpm to 46 bpm
Flat condition: 66 bpm to 66 bpm
Up condition: 66 bpm to 86 bpm

In Down and Up conditions, tempi of musical stimuli are gradually changed 2 bpm per 1 min, respectively. Changes of tempo are precisely reflected in each interval of musical beats. The format of the musical stimuli is Musical Instrument Digital Interface, and this format enables us to control the tempo of the musical stimuli independently.

2.2. Cardio-Music Synchrogram and Detection of Synchronization Periods

2.2.1 Cardio-Music Synchrogram (CMS)

CMS has been developed for observing the synchronization between musical beat and heartbeat [7]. Figure 1 shows how to construct the CMS. In the CMS, horizontal axis means time, vertical axis means musical beats. Heartbeats are represented on the development of musical beats. Especially in the Flat Condition, musical beats develops linearly against time development shown in bold line, and time of heartbeats are represented on the line. This process means heartbeat is represented as musical phase. After that, heartbeats on the musical phase are folded into three musical beats (modulo). If there is synchronization, parallel lines are observed in the CMS. As moduli, three, four, and five musical beats are used to construct CMSs.

2.2.2 Detection of Synchronization Periods

This sub-section briefly describes the detection of synchronization periods between heartbeat and musical beat by using CMS. To detect the synchronization period between musical beat and heartbeat, a statistical technique that is proposed by Kusunoki et al. is used [7]. The technique is based on statistical method and uses two synchrogram; normal synchrogram and hypothetic synchrogram between musical beat and heartbeat in a no-music condition. Synchronization periods are detected as rare period in hypothetic synchrogram. See the article [7] for further description of this detection method.

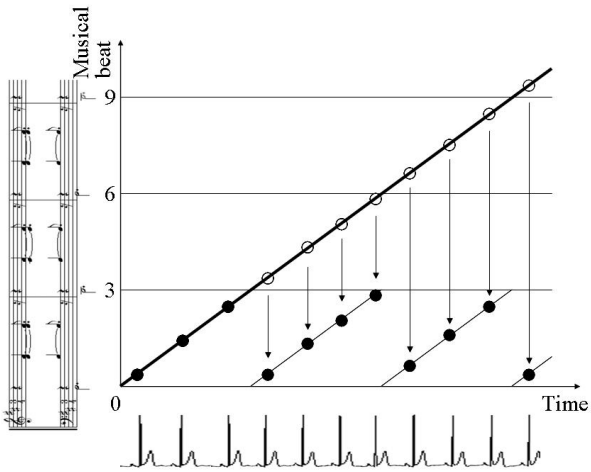

Figure 1: Construction of Cardio-Music Synchrogram.

3. Results

3.1. Synchronization period in Cardio-Music Synchrogram

Figure 2 shows the change of instantaneous heart rate and CMSs of a subject in Down condition. Tempo of the musical stimulus is represented as straight line from 0 s to 600 s in Figure 2(a). In Figure 2(b), synchronization periods are also shown in narrow boxes above each CMS. The black bold line in the narrow boxes indicates the detected synchronization periods. Instantaneous heart rate is defined as 60.0/(heartbeat interval), and time of the instantaneous heart rate is its time of prior heartbeat of the interval. These CMSs are based on three, four, and five musical beats respectively.

Parallel lines are observed in each CMS, and synchronization ratios are different; 5:4 (around 20 s and 100 s), 4:3 (around 50 s), and 1:1 (around 500 s). In down condition, number of parallel lines tends to increase in each CMS, because musical tempo decreases in accordance with time development.

3.2. Synchronization Period

To compare the total length of synchronization periods between conditions, averaged synchronization period in each subject and each condition are calculated. To summarize the synchronization periods obtained from three CMSs of each subject, overlapped synchronization periods between them is calculated for each subject.

Figure 3 shows average length of the total synchronization periods. According to the graph, shortest length of the synchronization period is observed in the Flat condition, and almost same length is observed in the Down and Up conditions. Significant effect of musical tempo on the length of the synchronization periods is observed with One-way repeated measure of Analysis of Variance.

3.3. Change of Heart Rate

To investigate the physiological effect by the listening musical pieces, change of heart rate is compared. Figure 4 shows difference of heart rate in 1 min before the listening period and 1 min after the listening period. Significant difference is not observed in the change of heart rate.

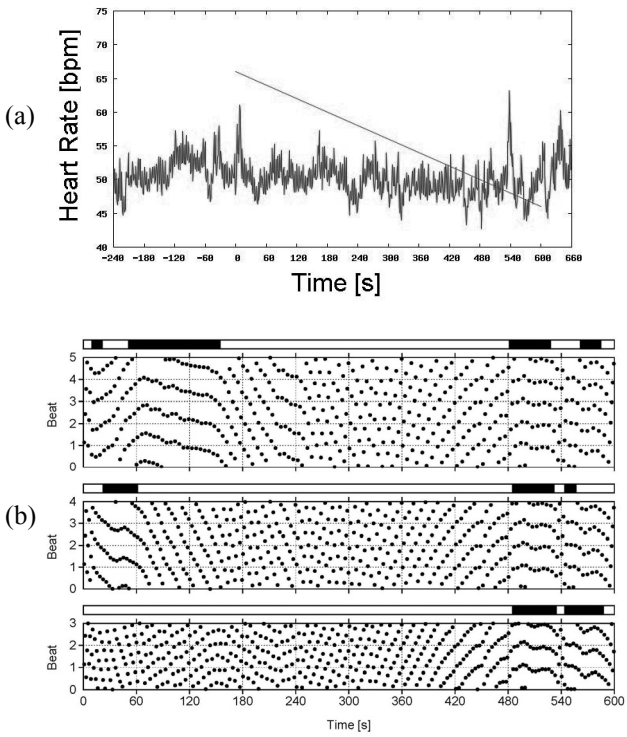

Figure 2: Example of (a) Instantaneous heart rate and tempo of musical stimulus and (b) Cardio-Music Synchrograms of a subject in Down condition.

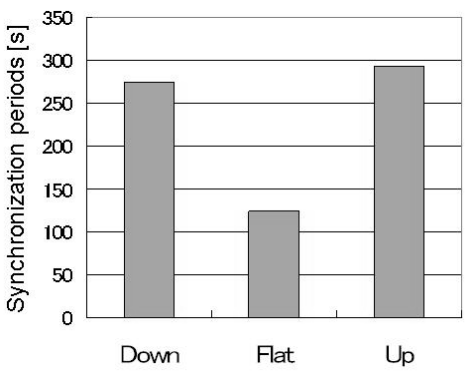

Figure 3: Length of synchronization periods.

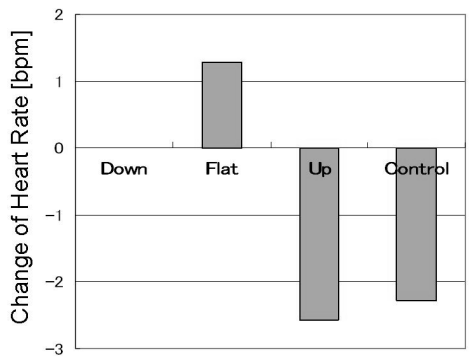

Figure 4: Change of heart rate between 1 min before and after 1 min.

4. Discussion

In Flat condition, the musical stimulus elicited shortest synchronization periods. There seem several synchronization ratios, therefore, change of the musical tempo in Up and Down conditions might search the periods that heartbeat synchronizes musical beat. The synchronization ratios are different between the subjects, and several kinds of synchronization ratios were observed in the CMSs.

The length of the synchronization periods did not mean the obvious change of heart rate. Although there was the difference of the length of synchronization periods between the conditions, change of the heart rate between before and after the listening musical stimuli was not observed. Nagashima et al. have investigated change of instantaneous heart rate in synchronization period and suggested decrease of heart rate in the period in Down condition [9]. Therefore, the synchronization, i.e. phase locking was considered as not successive phenomenon. Homeostasis, “an important function of the autonomic nervous system is to assist the body in maintaining a constant internal environment” [10], might affect on the coming off the synchronization.

The cause of the occurrence of the synchronization has not been clarified, however, we have hypothesis of the occurrence of the synchronization. Haas et al. have revealed the entrainment of the respiration by the musical tempo [11]. Furthermore, Schäfer et al. have revealed the synchronization between respiration and heartbeat in sleep [12]. These previous studies indicate the possibility of the synchronizing connection between heartbeat and musical tempo through the intermediation of the respiration. Some previous studies [13, 14] have suggested that relationship between velocities of musical piece affects the change of cardiovascular response. It is supposed that many musical factors affect on the change of heartbeat and the synchronization.

5. Conclusions

In this study, the synchronization between heartbeat and musical beat was investigated with three musical stimuli

made from same musical piece having different tempo. With CMS, synchronization periods were observed in all conditions. The comparison of synchronization periods between three conditions showed shortest synchronization period in Flat condition and significant effect of musical piece on the length of synchronization periods. The difference of the length did not concern with the change of heart rate in pre and post of listening musical pieces. The results of this study will contribute for theoretical use of musical piece by controlling a listener's physiological states.

Acknowledgments

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