synchronization, music, musical beat, heartbeat, Cardio-Music Synchrogram

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THE CHANGE IN THE SYNCHRONIZATION BETWEEN HEARTBEAT AND MUSIC

In this study, the change in the synchronization between heartbeat and music was investigated. The phenomena of the synchronization between human heartbeat and musical tempo has been reported in several previous studies, however, it has not yet been fully investigated including the effect of changing the tempo of musical piece on the synchronization. In the experiment, the subjects were exposed to musical pieces in which the tempo was manipulated to gradually increasing (named "Up" condition), decreasing ("Down") and constant ("Flat"). Through the analysis by our developed software, Cardio-Music Synchrogram, the shortest length of the total synchronization periods was observed in Flat condition. Furthermore, the temporal change in the synchronization was investigated.

1. INTRODUCTION

Musical pieces are often used for making atmosphere in various situations. Especially, relaxation effect of music is often used for reducing anxiety of patient, easing personal feelings, etc. Although some previous studies have partly revealed the psycho-physiological effect, the relaxation effect of music and its mechanism have not been clarified. To verify main effective factors of music, Hevner has compared the effectiveness of musical factors and clarified that tempo is the most effective factor on listener's impression [8]. Effect of musical tempo is generally realized as affecting listener's impression: fast tempo affords excitation feeling, and slow tempo affords relaxation feeling [10], respectively.

How does musical tempo affect listener's psycho-physiological states? Observing a relationship between tempo of music and physiological index of a listener may clarify the mechanism of effects of music. As a first trial, Bason et al. have investigated the relationship between simple sound and listener's heartbeat [1]. They have observed an entrainment of heartbeat intervals by interval of consecutive pure tones. Based on their finding, some previous studies have investigated the entrainment and synchronization of heartbeat by musical tempo [3, 4, 5, 6, 11, 12, 13, 15]. Kusunoki et al. have developed Cardio-Music Synchrogram (CMS), which is effective tool to visualize the synchronization between heartbeat and musical beat [11]. Fukumoto et al. have investigated the synchronization with relaxation musical pieces which changes its tempo [4, 5, 6].

In the previous study, three kinds of changes in tempo of musical pieces were used in listening experiments. However, concrete properties of the synchronization have not been clarified completely yet.

In this study, based on the previous study [6], the synchronization between heartbeat and musical beat is investigated in details. Same musical pieces with three different change in their tempo are used in the listening experiment. CMS is used for observing and analyzing the synchronization. The length of the synchronization periods and change in heart rate between three musical conditions are compared. Furthermore, temporal changes in synchronization state are observed. The synchronization would be used for several applications in the area of entertainment, therapy, media contents, etc.

2. METHOD

2.1. METHOD

This section describes the experimental procedure and musical stimuli used in the listening experiment.

2.2. SUBJECT AND PROCEDURE

Eight males participate in the listening experiment as subjects. All subjects don't have any special training of music.

The listening experiments are performed in a quiet room. All subjects individually participated in four experimental conditions. Each condition is composed of three sections; 4 min rest section1, 10 min musical section, and 1 min rest section2. In the listening section, the subjects listen to four different stimuli through headphone including three musical stimuli and no-music. The order of four experiment is randomized for each subject.

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 rest section1 and rest section2 are compared. To observe the synchronization between musical beat and heartbeat, CMS is

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constructed afterward of the all listening experiments. The length of synchronization periods is compared between three musical conditions. The change in the synchronization length in 1 min periods is also investigated.

2.3. MUSICAL STIMULI

All of three musical stimuli are made from same musical piece. Gymnopedy No.1 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 and ratio of change in tempo of three musical stimuli are defined by referring to the previous studies [4, 5, 6]. Tempi in three conditions 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 in tempo are precisely reflected in each interval of musical beats. The format of the musical stimuli is Musical Instrument Digital Interface.

2.4. CARDIO-MUSIC SYNCHROGRAM AND SYNCHRONIZATION PERIOD

To observe the synchronization between musical beat and heartbeat, CMS is used. Furthermore, synchronization periods are detected by using CMSs. This section describes construction of CMS and detection of synchronization periods from CMS.

2.5. CARDIO-MUSIC SYNCHROGRAM (CMS)

CMS has been developed for observing the synchronization between musical beat and heartbeat [11]. 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 like bold line shown in Fig. 1, and time of heartbeats are represented on the line. This process means development of heartbeat is represented in development of 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 (Fig. 2). As moduli, three, four, and five musical beats are used to construct CMSs.

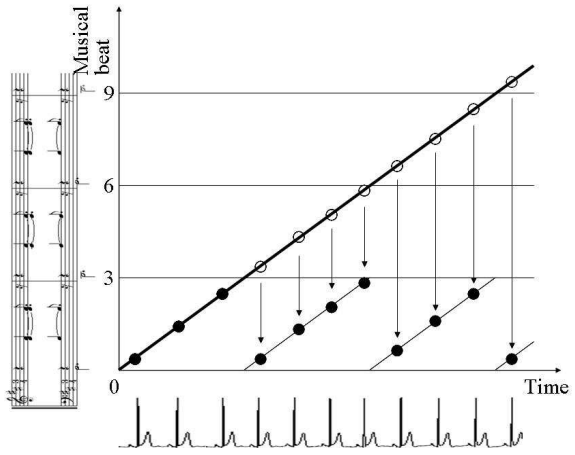

Fig. 1. Construction of Cardio-Music Synchrogram

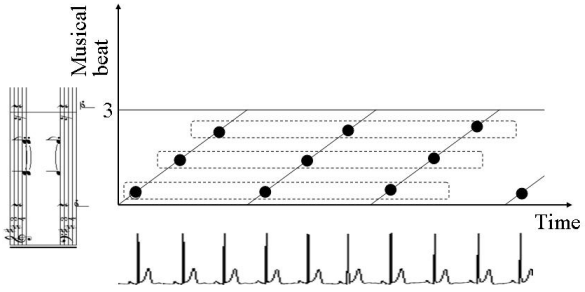

Fig. 2. An example of Cardio-Music Synchrogram in synchronization period

2.6. DETECTION OF SYNCHRONIZATION PERIODS

This sub-section briefly describes the detection of synchronization periods by using CMS. To detect the synchronization period between musical beat and heartbeat, a statistical technique proposed by Kusunoki et al. [11] is used. 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 (Significance level is set 0.05 in this study). See the article [11] for further description of this detection method.

3. RESULTS

3.1. SYNCHRONIZATION PERIODS IN CARDIO-MUSIC SYNCHROGRAM

Figure 3 shows the change in instantaneous heart rate (Fig. 3(a)) and CMSs (Fig. 3(b)) of a subject in Down condition. Tempo of the musical stimulus is represented as straight line from 0 s to 600 s in Fig. 3(a). In Figure 3(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 all CMSs, and synchronization ratios are different; 5:4 (around 10 s) and 1:1 (around 180 s and 500 s).

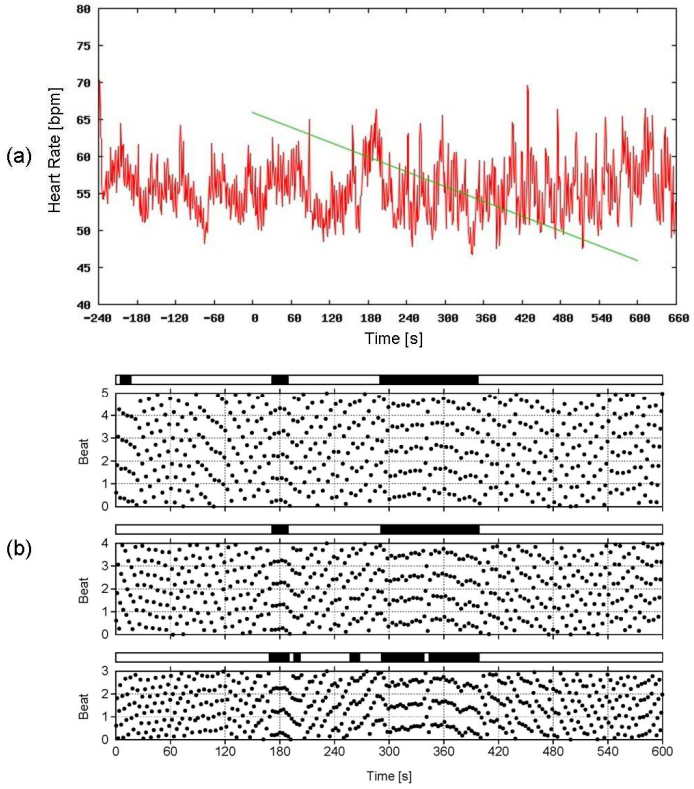

Fig. 3. An example of (a) heart rate in Down condition and (b) its Cardio-Music Synchrograms

3.2. LENGTH OF SYNCHRONIZATION PERIODS

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 4 shows average length of the total synchronization periods. According to this 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. Tendency of the effect of musical tempo on the length of the synchronization periods was observed with One-way repeated measure of Analysis of Variance.

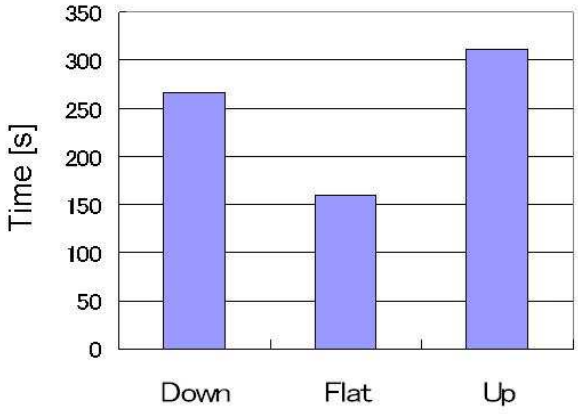

Fig. 4. Total length of synchronization periods in each condition

3.3. CHANGE IN HEART RATE

To investigate the physiological effect by the listening musical pieces, change in heart rate is compared. No significant difference of heart rate in 1 min before the listening period and 1 min after the listening period was observed.

3.4. TEMPORAL CHANGE IN SYNCHRONIZATION

To investigate the temporal change in the synchronization length, synchronization length in 1 min periods are observed in Down and Up conditions, in which long synchronization length were observed in section 3.2. Figure 5 shows the average of the synchronization length in each 1 min (60 s) period in Down and Up conditions respectively (Summation of the length in these periods means total length of the synchronization shown in Fig. 4).

In Down condition, peak of the synchronization length was observed in 300-360 s period, and the synchronization length tended to decrease in accordance with temporal development. In contrast, in Up condition, maximum length of the synchronization was observed in 540-600 s period, and the synchronization length tended to increase in accordance with temporal development. Statistical analysis is not applied to these results.

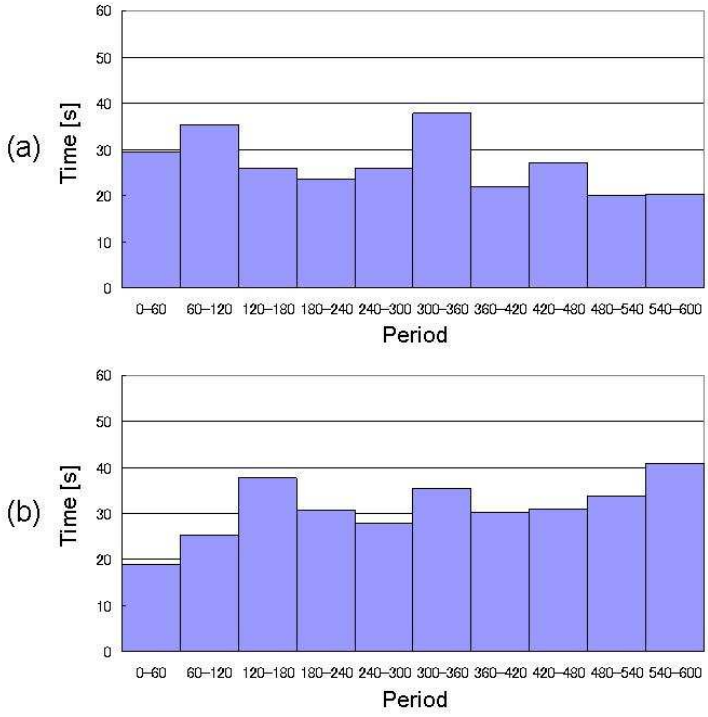

Fig. 5. Temporal change in synchronization length in each 1 min period in (a) Down condition and (b) Up condition

4. DISCUSSION

In the example of instantaneous heart rate and its CMSs in Down condition, different ratios of the synchronization were observed. This property of the synchronization with CMSs was observed in other subjects. The decrease of instantaneous heart rate was also observed around 480 s, and using a CMS with other basal musical beats (modulo) would visualize this synchronization. Furthermore, as shown in Fig. 3 (b), the synchronization was considered as intermittent phenomenon. Therefore, the existence of the synchronization did not result the change in heart rate. Homeostasis, maintains the constant internal conditions [14], might concern the intermittence.

Shortest total synchronization was observed in Flat condition. The total synchronization in Down and Up conditions were about 1.5 and 2.0 times as long as in Flat condition respectively. There seem several synchronization ratios for each subject, therefore, change in the musical tempo in Up and Down conditions might search the synchronization periods, and its resulted the difference of the total length of the synchronization between conditions.

The results of observing the temporal change in the synchronization showed the possibility of the changes in the synchronization length in accordance with temporal development. In the previous study, the synchronization length is supposed to be increased in accordance with temporal development [6], however, the results of this study were different from the supposition. The result of the temporal change in the synchronization was the average between the subjects, therefore the result did not reflect the individual differences. Further investigation reflecting the individual difference is needed to clarify the change in the synchronization precisely, because there was a difference in the total length of the synchronization between subject.

As the cause of the synchronization has not been clarified, we have a hypothesis that connect the results of two previous studies. One of result was the entrainment of the respiration by the musical tempo [7] and the another was the synchronization between respiration and heartbeat in sleep [16]. These results indicate the possibility of the synchronization between heartbeat and musical tempo through the intermediation of the respiration. Some other previous studies [2, 9] have suggested the effect of velocity of music on temporal change in cardiovascular response, therefore, many musical factors are considered as relating the synchronization.

5. CONCLUSIONS

In this study, the change in the synchronization between heartbeat and musical beat was investigated with three musical stimuli. These musical stimuli were made from same musical piece having different change in its tempo. With CMS, synchronization periods were detected in all conditions. The comparison of the synchronization periods between three conditions showed shortest synchronization period in Flat condition and tendency of the effect of musical piece on the total length of synchronization periods. The difference of the length did not concern with the change in heart rate in pre and post of listening musical pieces. Furthermore, the temporal change in the synchronization were observed in Down and Up conditions. The results of this study will contribute for theoretical use of music by controlling listener's physiological states with musical piece and its tempo.

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