AN EVALUATION OF THE RELAXATION EFFECT OF MUSIC BASED ON THE RELATIONSHIPS BETWEEN THE CONDITION OF PULSE AND MUSIC TEMPO USING THE EEG AND HRV BASED INDICATORS

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Abstract: This paper attempt to investigate the relationships between relaxation effect of music and rhythm of human body (in this paper fingerplethysmogram (so called ”pulse”) is adopted) using EEG and HRV based two relaxation indicators. We focus on following viewpoints: synchronization between pulse and music, the tendency of pulse beat and pulse-music tempo ratio (μ). This paper reports the experimental results that the pulse decreasing state is effective for EEG based indicator while HRV based indicator is high value at the pulse increasing state. Furthermore, we classify subjects into 3 groups by the analysis of synchronization between pulse and music tempo. This papar also reports the analysis of relationships between pulse-music tempo ratio (μ) and relaxation effect under the classification.

1 INTRODUCTION

Nowadays, ”Kansei” (emotion, feelings) evaluation has become more important keyword because many products are used by human and its feeling effects good or bad impression for the user. Many researchers are now researching the design and another factors bringing us better feelings. However, it is difficult to evaluate emotions because there are too many variations in ”emotion” and there is no general way to describe it. On the other hand, the objective way of evaluating emotion is studied in many institutes using bio signals. To evaluate the feelings, many indicators are adopted. For example, brain wave is popular one. Alpha wave of brain waves is usually adopted as a indicator of relaxation. In the ”Kansei” evaluation, a study about relaxation effect is performed flourishingly because many people needs relaxation in this demanding society. We focused on the relaxation effect of music because we can get the music relaxation easily sitting at the sofa in the house and no any special equipment is needed. (T. Nakamura, 2002) described the relationships between the tone of the sound and power spectrum of the alpha wave using electroencephalography (EEG). On the other hand, investigation on musical tempo and impression change using subjective valuation has been reported (K. Kurashima, 2004). In the other case, the substance in saliva is used as a indicator of stresses. Music research is also performed in many viewpoints because music has so many elements: rhythm, tempo, harmony, instrumental and more. Various researches focused on the music tempo has been reported. For example, synchronization between pulse and music tempo is described in (M. Fukumoto, 2004). The paper stated that synchronization effect is related to relaxation effect calculated from heart rate variability. In this paper, we try to investigate the relaxation effect of music based on the relationships between the rhythm of human body and music tempo in addition to synchronization effect, and report many empirical results about relaxation effect.

2 SUBJECT OF ANALYSIS

Relaxation indicators:
In this paper, we adopted electroencephalography (EEG) and heart rate variability (HRV) to calcualte relaxation indicators. EEG analysis was performed using the HSK central rhythm monitor system devel-

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Figure 1: Brain wave and pulse sensor.

oped by Human Sensing Inc in Japan.

This equipment measures the Fp1 and Fp2 channels of the EEG and estimates the Comfortable-Degree (CD) (Yoshida, 2000). Ordinarily, EEG is measured with the International 10:20 method, but we adopted the method described in (Yoshida, 2000) because it lightens a burden of the subject. We used the content ratio of high frequency (HF) as the HRV indicator calculated from the finger plethysmogram (simply called, pulse).

- Comfortable-Degree
  We used Comfortable-Degree as an indicator of relaxation at brain. This indicator is calculated from the frequency fluctuation of the brain waves. Tomoyuki Yoshida tried to make a indicator of comfortable-feelings (Yoshida, 2000). He insisted that human psychological condition changes every time if the physical situation was same. So we have to evaluate the fluctuation of the human emotion in an objective way. The research groups performed the experiment that exhibit many good or bad smells, sounds and musics for the subject and investigated the fluctuation of the alpha wave frequency. According to the result, the gradient of the spectrum of brain waves in the left frontal area is get closed to 1.0 in the situation of comfortable. Conversely, that is get closed to 0 in the situation of uncomfortable. On the other hand, the gradient of the spectrum of brain wave in the right frontal area is get closed to 0 in the condition of subject felt awakening. As a result, the expression of comfortable degree is consisted below.

  $$CD(\%) = \sqrt{Fp1_{slope}{}^2 + Fp2_{slope}{}^2}/2 * 100, \quad (1)$$

  where $Fp1_{slope}$ and $Fp2_{slope}$ mean the gradient of the spectrum of alpha wave in Fp1 and Fp2 channel, respectively.

- Content Ratio of HF
  Our heart beat is varying every time and R-R Interval (peak to peak) also changes every time. Many researches focused on this phenomenon clarified that the changes of R-R interval is related to autonomic nerve system (Task Force of the European Society of Cardiology, 1996). This evaluation method is called Heart Rate Variability (HRV). The method is performed following steps.
  - calculate R-R interval from pulse data (shown in Figure 2).

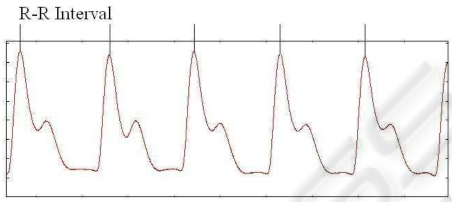

Figure 2: A sample of pulse data.

  - generate an interpolated R-R interval line (shown in Figure 3).

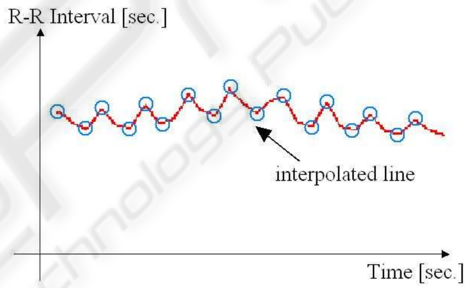

Figure 3: Interpolated R-R line.

  - Apply the Coarse Graining Spectral Analysis (CGSA) (Y. Yamamoto, 1991)(Y. Yamamoto, 1993) to make the indicator of autonomic nerve system clear.
  - In CGSA method, FFT is performed to obtain the frequency power spectrum.
  - separate the spectrum into Low frequency (From 0.024 Hz to 0.15 Hz) and High frequency (From 0.15 Hz to 0.6 Hz).

  We used Content Ratio of HF as an indicator of relaxation at body. LF/HF is used as an indicator of the sympathetic nervous system (SNS). Content ratio of HF, i.e., $HF/(HF+LF)$, is used as an indicator of the parasympathetic nervous system (PNS) that is also used as a relaxation indicator because parasympathetic nervous system is dominant during relaxation. We calculated the content ratio of HF by the HRV method from the pulse.

Relationships between pulse and music:

- Synchronization between pulse and music tempo
  (Y. Kusunoki, 2003) stated the synchronization phenomenon between pulse and music tempo

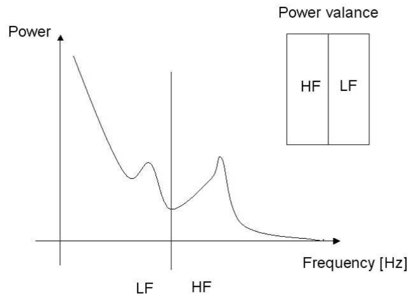

Figure 4: Spectrum of HF/LF valance (in rest).

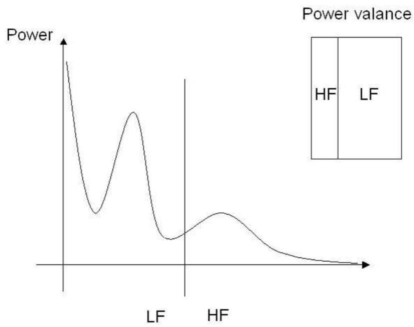

Figure 5: Spectrum of HF/LF valance (in tilt).

(Later, it is simply called as "synchronization") as a relationship between pulse and music tempo. (M. Fukumoto, 2004) explained that synchronization period is the period where the ratio between heart rate and the number of music beats is kept constant, and indicated that a total of the short synchronization periods in the music experiment were significantly larger than in the control experiment. For example, a state that the subject's pulse beats 3 times while a certain music played in one musical unit continues for a certain period of time (see Figure 6).

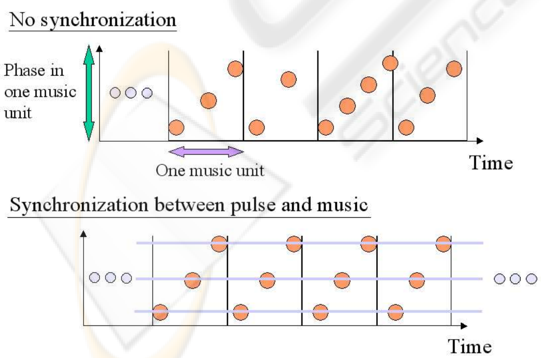

Figure 6: Example of synchronization.

To analyze the synchronization between pulse and music tempo, we adopted the method described in (Y. Kusunoki, 2003). The data (relaxation indicator) obtained are classified into three groups: no sound, no synchronization, pulse and music synchronization. In addition to this classification, no synchronization state is further more classified into two groups; pulse beat increased and pulse beat decreased.

- Pulse-Music Tempo Ratio
  In this paper, we introduce a scale that is called the pulse-music tempo ratio. By classifying the condition of the subject from the pulse-music tempo ratio, we can evaluate the relationships between relaxation indicator and the state of the subject' s pulse and the tempo of music. Musical tempo T in every minute is expressed by the sequence T_j ($j = t_m, t_{m+1}, \ldots, M$), where j is the minute with music presence, t_m is the starting minute of music presence, and M is the total minutes of measurement. Subject i' s average value of each indicator in the j-th minute is described as $CD_{i,j}$ and $HF_{i,j}$. The average value of each indicator in all listening terms is described as $\overline{CD}$ and $\overline{HF}$. Subject i' s average pulse beats in the j-th minute is described as $P_{i,j}$. Then, we denote the pulse-music tempo ratio as $\boldsymbol{\mu}_i$. The $\boldsymbol{\mu}_i$ value for subject i is calculated every minute using the following equation:

$$\boldsymbol{\mu}_i = \{\mu_{i,t_m}, \mu_{i,t_{m+1}}, \ldots, \mu_{i,M}\}, \tag{2}$$

where

$$\mu_{i,j} = P_{i,j}/T_j, \tag{3}$$

For example, (Reinhaldt, 1999) reported that synchronization is well observed in the 2:3 state of pulse and music tempo ratio. In this case, 2:3 state of the pulse-music tempo ratio corresponds to $\mu = 1.5$.

Finally, we define the efficiency values τ_{HF} and τ_{CD} for each indicator calculated from the following equations:

$$\tau_{HF}(\mu) = \frac{\Sigma_{i=1}^{N}\Sigma_{j=t_m}^{M}\{s(\mu_{i,j},\mu)comp(HF_{i,j},\overline{HF})\}}{\Sigma_{i=1}^{N}\Sigma_{j=t_m}^{M}\{s(\mu_{i,j},\mu)\}}, \tag{4}$$

$$\tau_{CD}(\mu) = \frac{\Sigma_{i=1}^{N}\Sigma_{j=t_m}^{M}\{s(\mu_{i,j},\mu)comp(HF_{i,j},\overline{HF})\}}{\Sigma_{i=1}^{N}\Sigma_{j=t_m}^{M}\{s(\mu_{i,j},\mu)\}}, \tag{5}$$

where N is the number of subjects, and

$$s(\mu_1,\mu_2) = \left\{ \begin{array}{ll} 1 & (0 \leq \mu_1 - \mu_2 < K) \\ 0 & otherwise \end{array} \right. , \tag{6}$$

$$comp(a,b) = \left\{ \begin{array}{ll} 1 & (a > b) \\ 0 & otherwise \end{array} \right. \tag{7}$$

In this definition, τ is the ratio of the frequency where each indicator ($HF_{i,j}$, $CD_{i,j}$) is higher than its average value ($\overline{CD}$, $\overline{HF}$) to the frequency where $\mu_{i,j}$ is classified into μ. Function s classifies the condition of $\mu_{i,j}$ into each value of the pulse-music tempo ratio by the appropriate value K.

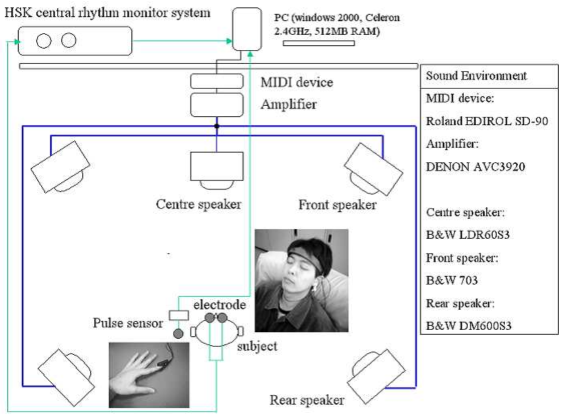

Figure 7: Experiment environment.

3 EXPERIMENT PROCEDURE

The subjects were 12 males in their 20s ($N = 12$). During the experiment, the subjects sat on a sofa and closed their eyes. The experiment consisted of two parts. In the first 4 min, no sound was presented, and then music was played for the next 10 min ($t_m = 5$ and $M = 14$). The experimental environment is shown in Figure 7. We presented an MIDI (Musical Instruments Data Interface) digital file 'Gymnopedie, No.1 (E. Satie)' as the musical stimulus, as used in (M. Fukumoto, 2004), and the tempo of the music was gradually decreased from 66 to 48 BPM every minute. The filter of the EEG analysis system was adjusted to the following settings; low pass filter: 13 Hz, high pass filter: 8 Hz. During the period of the experiment, a finger plethysmogram (simply called 'Pulse') that sampled at 500 Hz was measured from a subject's forefinger. The analog data obtained were translated to digital data and transferred to a PC through an USB port. To detect the synchronization of musical tempo and pulse, we adopted the method described in (Y. Kusunoki, 2003). The output signal from the MIDI device was transferred to the amplifier through a fibre optical cable. The volume of sound was fixed at a level that was not annoying for the subject.

4 RESULTS AND DISCUSSION

4.1 Analysis by Time

Measured average pulse tempo and presented music tempo is shown in Figure 8. Figure 8 indicate that the average value of pulse beat decreased 2.9 BPM in all the listening term, while the change of pulse beat includes the individual differences.

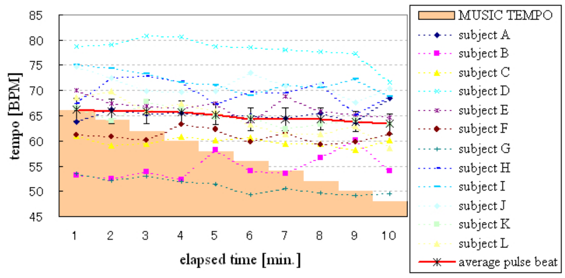

Figure 8: Music tempo and pulse tempo.

In next section we tried to analyze the relaxation indicator for each state of the subject using the pulse-music tempo ratio. According to the variance of the obtained pulse-music tempo ratio ($\mu_{i,j}$), we considered $K = 0.1$ to be appropriate to classify $\mu_{i,j}$ values in this experiment.

4.2 Analysis by Synchronization

The experimental results have some different tendencies of synchronization. So we classified observation type of synchronization into 3 groups (shown in Fig. 9): observed at low ratio, observed at high ratio and observed in wide range of ratio. In this paper "ratio" means the pulse-music tempo ratio.

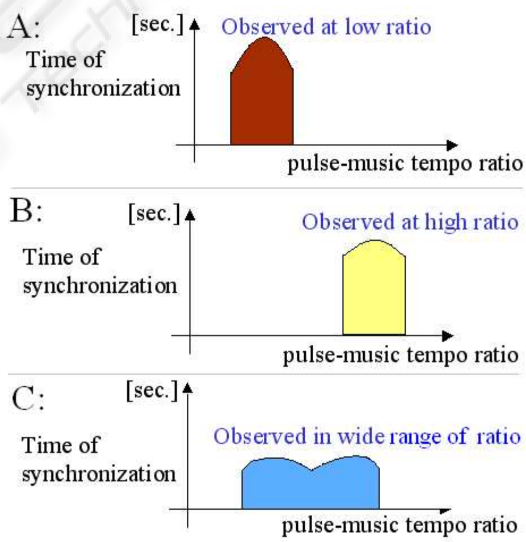

Figure 9: Classification of synchronization.

Experimental result of synchronization were classified into 3 groups shown in from Fig. 10 to Fig. 12. The number of person in each groups is following:

- group A(observed at low ratio): 4 subjects
- group B(observed at high ratio): 3 subjects
- group C(observed in wide range of ratio): 5 subjects

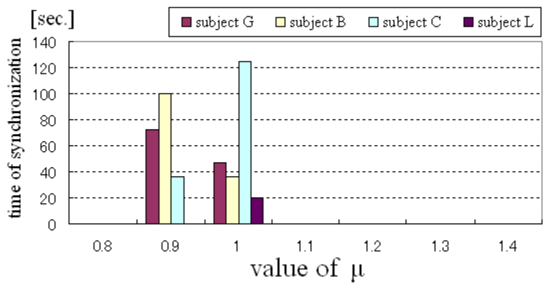

Figure 10: Synchronization observed at low ratio (type A).

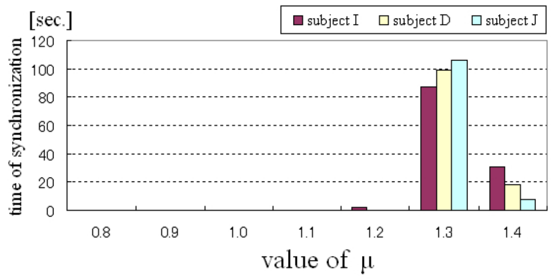

Figure 11: Synchronization observed at high ratio (type B).

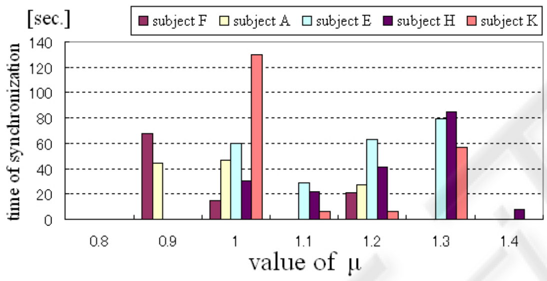

Figure 12: Synchronization observed at wide ratio (type C).

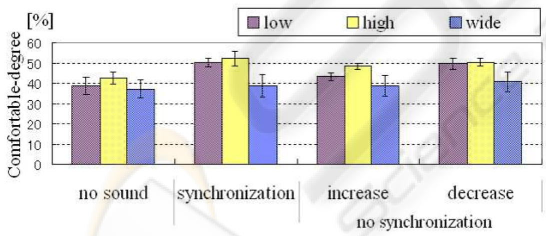

Figure 13: Synchronization and pulse tendencies and changes of *CD (each groups).*

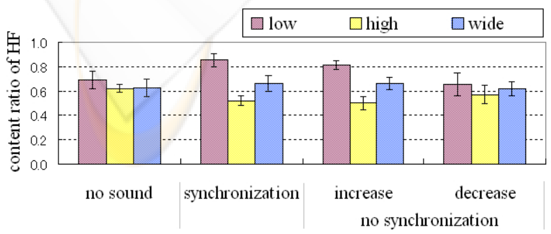

Figure 14: Synchronization and pulse tendencies and changes of *HF (each groups).*

Synchronization is observed in spread μ area as shown in figures. There is no correlation between synchronization occurrence and pulse-music tempo ratio. But the pulse-music tempo ratio that synchronization is well observed exists for each subject and the range has large individual differences (see Fig. 10, 11 and 12).

Next we considered the tendency of the pulse beat. In this paper, we adopted the gradient of the instantaneous pulse beats in every minute as an indicator of the pulse beat tendency as well as synchronization. Experimental result of Comfortable-degree and content ratio of HF were classified into four groups: no sound, tempo and pulse synchronization, pulse decrease at no synchronization, pulse increase at no synchronization, shown in Fig. 13 and 14.

In Figure 13, the changes of Comfortable-degree in type C (”observed in wide ratio” group) is smaller than the other groups. The results in Figure 13 says that Comfortable-degree is higher in both of synchronization state and pulse decreasing state. Furthermore, Comfortable-degree with listening to music (involves synchronization and no synchronization) is higher than no sound state. As well as Comfortable-degrees, Figure 14 indicates that the changes of content ratio of HF in type C group is smaller than any other groups. On the other hand, content ratio of HF is higher at the synchronization state same as reported in (M. Fukumoto, 2004). Comparing two indicators (Comfortable-degree and content ratio of HF), the tendency of content ratio of HF is uneven with Comfortable-degree. The relationships among relaxation effect and synchronization and pulse tendency in all group is shown in Figure 15 and 16.

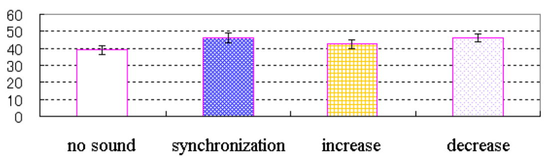

Figure 15: Sync. pulse tendency and *CD.*

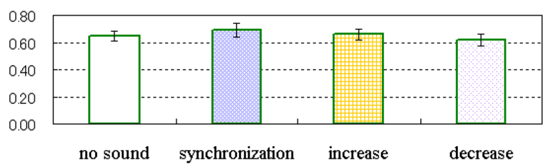

Figure 16: Sync. pulse tendency and *HF.*

We first considered the variance of each relaxation indicators. The result indicates that HF increases in the synchronization state, that is same as the result of each groups. However, the HF value in the no sound state is higher than that in the pulse decreasing state of no synchronization. On the other hand, Comfortable-degree in both the synchronization and no synchronization was higher than that in the no sound state. This result implies that decreasing of the pulse tempo is as important as synchronization.

4.3 Analyze by Pulse-music Tempo Ratio

In this section, we calculated μ_i from the pulse tempo $P_{i,j}$ for all subjects and the musical tempo T_j, and the frequency ratios τ_{CD} and τ_{HF} from the relaxation indicators ($HF_{i,j}$,$CD_{i,j}$) for all subjects with the following μ values ($\mu = 0.8, 0.9, 1.0, \ldots, 1.4$).

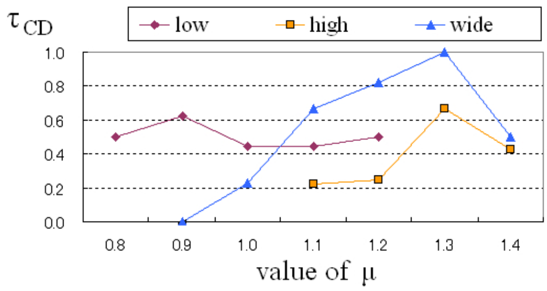

Figure 17: τ_{CD} in each group.

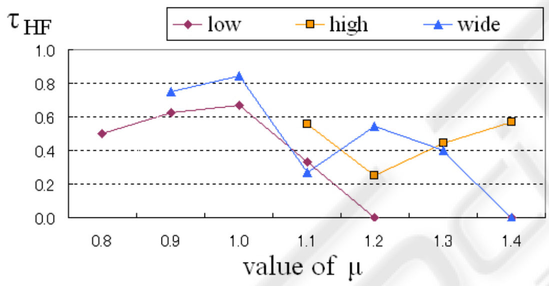

Figure 18: τ_{HF} in each group.

At first, the relationships between μ and τ_{CD}, τ_{HF} every groups (see Fig. 9) are shown in Figure 17 and Figure 18. The result in Figure 17 indicate that the effect for Comfortable-degree in type A group (”observed at low ratio”) changed constantly in observed pulse-music tempo ratio. In the other groups, Comfortable-degree was higher in the ratio around $\mu = 1.3$. In comparison with Comfortable-degree, content ratio of HF was more effective in lower pulse-music tempo ratio (around $\mu = 1.0$).

5 CONCLUSIONS

In this paper we reported the relationships among relaxation effect, pulse tempo and musical tempo based on two relaxation indicators. Experimental result indicate that the pulse decreasing state is effective for comfortable-degree calculated from brain waves as well as synchronization state. On The other hand, content ratio of HF calculated from pulse is high value in pulse increasing state. In analysis of synchronization, the tendency of synchronization occurrence is classified into 3 types. The analysis of pulse-music tempo ratio showed that each relaxation indicator has optimum μ value. According to these result, we suggest a new way of using music for relaxation. That is, selectively presenting music with slower tempo than the user’s pulse when the user wants the brain relaxation, or music with a tempo near to the user’s pulse when the user wants body relaxation. If there is a music music that has both two characteristics, that kind of music is better for us. In the future work, we will attempt to generate innovative music that depending on the tempo of the user’ s pulse at the beginning of music, the tempo of music is gradually decreased to $\mu = 1.3$. We will study whether that kind of music is effective for both content ratio of HF and Comfortable-degree.

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