A Study on Melody Tempo with EEG

Yuan Yuan, Yong-Xiu Lai, Dan Wu, and De-Zhong Yao

Abstract—In this paper, tempo perception is investigated by recording spontaneous electroencephalograph (EEG). Ten normal male non-musician college students are selected according to questionnaire results after listening absorbedly to four different tempos of an excerpt from a Mozart sonata. EEGs are recorded when the subjects are listening to the music. The EEG spectral power (SP) is analyzed for alpha band. The varying trend of power spectrum during exposure to music excerpts of different tempos is studied and shows the consistence with the previous tempo-specific hypothesis: a tempo-transformed performance will sound less natural than an original performance does. The results presented in this paper suggest that tempo is an important factor that could influence the alpha rhythm.

Index Terms—Electroencephalograph alpha power, music and Electroencephalograph, tempo perception.

1. Introduction

Music is an element ceaselessly presented in daily human life. In the early 20th century, several studies focused on the importance to the effect of tempo. Hevner, from all variables, concluded that tempo was “of greatest importance in carrying the expressiveness in music”[1]. Rigg suggested that “tempo is the most important feature in determining the mood effects of music”[2][3]. Originally, one might expect rhythm to scale proportionally with tempo in production and to be perceptually invariant under tempo transformation. Existing perceptual studies have presented rather inconclusive evidence[3][4], especially in the domain of expressive timing. Some studies found expressive timing to be nearly invariant under tempo transformation[3], which is interpreted as “relational invariance” (or proportional duration), a key concept in research on timing control in skilled motor performance[5].

However, several studies have shown that this was not always the case[6]. Through a rating task for subjects to rank the quality of classical music pieces, including the original ones and manipulated ones (tempo range: 20% or −20%), Reed found that in most cases, the original interpretations scored better than the manipulated versions[4]. Other authors also showed that global tempo did influence expressive timing (i.e., timing being tempo specific): at different tempi, different structural levels became salient, and had an effect on the expressive freedom and variability observed[7][8]. As to the issue Honing proposed that whether the original tempo was specific, the “tempo-specific timing hypothesis” will be supported if a significant proportion of the subjects are able to identify the original version[9]. This hypothesis based on the idea that expressive timing in music performance is intrinsically related to global tempo. When expressive timing is simply scaled to another tempo (i.e., slowed down or sped up proportionally), the performance might sound awkward or unnatural, and hence easier to identify as a tempo transformed version. In other words, a performance that has been tempo-transformed might sound awkward since the expressive timing is not adapted in the way a musician would normally do.

The present study investigated whether expressive timing is perceptually invariant under tempo transformation by analyzing electroencephalograph (EEG) alpha band spectral power (SP). Many researches related to brain have proved the importance of alpha band. The power of alpha rhythm is negatively correlated with brain activity, namely larger alpha power denotes less EEG activity, and vice versa[10]. Activity within the alpha range (typically 8 Hz to 13 Hz) may be inversely related to underlying cortical processing since decreases in alpha tend to be observed when underlying cortical systems engage in active processing[11]. And alpha power has more capability of reflecting the brain activity than other bands[12]. Some studies investigated the relationship between brain and music by analyzing alpha band. Decreased alpha activities have been found when listening to pleasant musical pieces[13][14].

The significance of research on alpha band does not only apply in the academic study, but also have been utilized widely in clinical area. Sufferers of obsessive-compulsive disorder exhibit frontaly decreased alpha powers, and their EEG band powers tend to correlate positively with obsessions and negatively with compulsions[15]. Alpha bands is also important in the realms of music therapy and music biofeedback, alpha training
augments psychotherapy in the recovery from addictions, post-traumatic stress disorder, and other disorders. Alpha training can facilitate healing in the psychological domain, or enhance performance.

The main goal of this work is to study EEG spectra of the alpha band in the state of quiet wakefulness with open eyes during listening to different tempo versions. We strive to explore how alpha band power changes when musical tempo alters. Specifically, we will study how musical tempo could modulate EEG alpha power through experiments.

2. Materials and Methods

2.1 Subjects

Using related questionnaire, 10 subjects selected from 121 volunteers (age = 22.37 ± 1.97 years, range = 20-24 years) participated in and successfully completed this study. All were right-handed, healthy, and without musical training; none was used to listening to this musical composition chosen in the experiment, did not have a history of mental or neurological problems.

The questionnaire mainly concerns the following points. What genre does the volunteer prefer? How often does the volunteer listen to music in daily life? After listening attentively to the music. First, the EEGs of rest condition with open eyes were recorded for 2 minutes. Then, four musical stimuli with different tempos of this music excerpt (3 min) presented by a computer binaurally through a headphone in a fixed order of musical tempo as follows: 26 beats per minute (bpm), 52 bpm, 78 bpm, and 138 bpm; volunteers were asked to distinguish which one is the original performance. The qualified volunteers selected for the following EEG experiment must reach these qualifications: preferring western classical music; listening to music at least every other day; having the ability to identify the original performances.

2.2 Experiment Design

The experiment was performed in a quiet room where subjects were told about the EEGs procedure and instructed to listen attentively to the music. First, the EEGs of rest condition with open eyes were recorded for 2 minutes. Then, four musical stimuli with different tempos of the same music excerpt were presented by a computer binaurally through a headphone in a same order of musical tempo as questionnaire. The EEGs in musical conditions were all recorded with open eyes.

2.3 EEG Measures

The EEGs data were collected using a 128-channel commercial EEG system (EGI System 200), with scalp-electrode impedances ranging from 10 kΩ to 40 kΩ. The data were digitized with a sampling frequency of 500 Hz (0.1 Hz low-pass filter and 48 Hz high-pass filter). The reference electrode was located at the top of the head (Cz).

In this study, 19 scalp-electrodes were selected for EEG signal analysis, denoting different regions separately: frontal areas (Fp1, Fp2, Fz, F3, F4, F7, and F8), central areas (Cz, C3, and C4), temporal areas (T5, T6, T3, and T4), parietal areas (P3 and P4), and occipital areas (O1 and O2).

2.4 Data Processing and Analysis

EEGs data (24s), free of artifacts such as eyes and head movements, were chosen from the raw data of each subject in each music excerpt for the following analysis. As to each electrode, the SP was calculated using Welch procedure and was analyzed in the standard physiological frequency band: alpha (8 Hz to 13 Hz) ($SP_{\text{orig}}$) is a power spectrum during exposure to the original tempo music excerpt (52 bpm); $SP_{\text{mid}}$ is the mean value of SPs during exposure to the music excerpts of middle bias tempo between 26 bpm and 78 bpm; $SP_{\text{ult}}$ is a power spectrum during exposure to the ultimate bias tempo music excerpt (138 bpm). The significance of within-subject differences among those three groups was estimated by the repeated measures analysis of variance. The SPs with significant differences were further analyzed with multiple comparisons using Tukey’s post hoc test to compare the SPs of the three groups. A significance level of $P<0.05$ was used in all comparisons. EEGs analysis was performed using Matlab 7.4.0 and statistical analysis was performed using SPSS 13.0.

3. Results

Among those three groups, significant changes of EEGs alpha power appear in many regions, especially frontal areas and left-hemisphere areas. In these regions, as to each scalp-electrode, the varying trend of EEG alpha power exhibits $SP_{\text{orig}} > SP_{\text{mid}} > SP_{\text{ult}}$. The topography for the mean values of alpha power of those three groups is shown in Fig. 1. The alpha power values in electrodes with significant difference among those three groups are listed in Table 1.

Meanwhile, as to each electrode, the SPs with significant differences were estimated by Tukey’s post hoc test. We find that EEG alpha power during listening to the original tempo music excerpt is greater than that during listening to the middle bias tempo music excerpt, especially in left frontal and temporal areas, and that during listening to the ultimate bias tempo music excerpt, especially in the frontal and left-hemisphere areas; but the difference of EEG EEG alpha powers is not significant during listening to the middle bias tempo music excerpt and during listening to the ultimate bias tempo music excerpt.

Fig. 1. The topography of the alpha power of the three groups (left: original tempo, middle: middle bias tempo, and right: ultimate bias tempo).
Table 1: Mean alpha power values in electrodes with significant difference among the three groups

<table>
<thead>
<tr>
<th>Region</th>
<th>Original tempo</th>
<th>Middle bias tempo</th>
<th>Ultimate bias tempo</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fz</td>
<td>19.54</td>
<td>18.91</td>
<td>18.83</td>
<td>(P&lt;0.05)</td>
</tr>
<tr>
<td>F3</td>
<td>19.01</td>
<td>18.33</td>
<td>18.23</td>
<td>(&lt;0.05)</td>
</tr>
<tr>
<td>F4</td>
<td>18.91</td>
<td>18.30</td>
<td>17.95</td>
<td>(&lt;0.05^\ddagger)</td>
</tr>
<tr>
<td>P3</td>
<td>20.02</td>
<td>19.12</td>
<td>18.78</td>
<td>(&lt;0.05^\ddagger)</td>
</tr>
<tr>
<td>O1</td>
<td>21.05</td>
<td>20.53</td>
<td>20.26</td>
<td>(&lt;0.05)</td>
</tr>
<tr>
<td>F7</td>
<td>19.20</td>
<td>18.70</td>
<td>18.34</td>
<td>(&lt;0.05^\ddagger)</td>
</tr>
<tr>
<td>F8</td>
<td>18.46</td>
<td>17.91</td>
<td>17.18</td>
<td>(&lt;0.05^\ddagger)</td>
</tr>
<tr>
<td>T3</td>
<td>18.65</td>
<td>18.41</td>
<td>17.84</td>
<td>(&lt;0.05^\ddagger)</td>
</tr>
<tr>
<td>T5</td>
<td>21.56</td>
<td>20.50</td>
<td>20.18</td>
<td>(&lt;0.05^\ddagger)</td>
</tr>
</tbody>
</table>

Note: "#" denotes significant difference of the SP between the original tempo and the middle bias tempo; "\(\ddagger\)" denotes significant difference of the SP between the original tempo and the ultimate bias tempo.

4. Discussion

From early study, we know that the performance in original tempo sounds natural and the performance in tempo-transformed version might sound awkward and unnatural, even non-musician subjects could distinguish original performances from tempo-transformed versions\(^{[5]}\). In our statistical results, we find that the EEG alpha power decreases from original tempo data to middle bias tempo data then to ultimate bias tempo data. An underlying assumption in emotion EEG research is that the increase of alpha activity is associated with the decrease of cortical activity in relative cortical region\(^{[6]}\). When subjects listen to tempo-transformed music, brains are related to re-integration and task identification, so middle bias tempo version and ultimate bias tempo version need more brain resource to process these perception information after the tempo transformed. Therefore, the alpha power for original music is greater than that for tempo-transformed version, and alpha power decreases with the increase of the proportion of the deviation from original tempo.

Other researches\(^{[10]}\) show that the increase of the frontal EEG alpha power is associated with the decrease of the musical emotion intensity, and that there is a certain relationship between the change of EEG activity and the musical emotion intensity. The original tempo music sounds natural and could be identified easily, so it arouses lower brain activity; similarly, tempo-transformed version sounds natural and weird, thus it arouses relatively higher brain activity. Our results accord with the conclusion of previous study in the realms related to emotion and EEG. Therefore, our study severs as a helpful supplement to early study concerning tempo-specific hypothesis because almost all early related studies were based on the behavior analysis and they focused on music perform rather than music cognition.

In brain left-hemisphere, we also find a significant difference appearing among different music stimulus conditions (original tempo, middle bias tempo, and ultimate bias tempo). According to the literature data, greater EEG changes in professional musicians during listening to music take place in the left hemisphere, whereas, in subjects who are not professional musicians, greater EEG changes are observed in the right hemisphere\(^{[11]}\). Although all subjects who took part in our experiments are non-musician, the main reason why the significant difference exists in the left hemisphere is that the whole experience is not only an emotional perception, but also an identification of original tempo music piece. Some research has reported that rhythm and pitch discrimination are processed mainly in the left hemisphere\(^{[17]}\). That is, non-musician subjects perhaps have more brain activities in left hemisphere when they are asked to accomplish some complex tasks, such as identifying the original tempo music piece.

From the result of Tukey’s post hoc test, we observe that there is the most obvious difference when comparing tempo-transformed version with original version, namely between original version and middle bias tempo version or ultimate bias tempo version. However, the difference of EEG alpha powers between during listening to the middle bias tempo music excerpt and during listening to the ultimate bias tempo music excerpt is not enough to produce significant level in any electrode location. According to the above observation, it is assumed that different function mechanisms could be utilized to process and control the original tempo version and the tempo-transformed version.

In addition, the results achieved in this paper not only support the tempo-specific hypothesis, but also provide a preliminary theory proof used in alpha biofeedback realm. Recent reports indicate that EEG biofeedback can improve abilities of reading, writing, drawing, and calculating through lowing alpha brainwaves, furthermore, alpha neurofeedback has successfully been applied both in treating addictions and in enhancing artistry in music students\(^{[18]}\). It is believed that subsequent attempts will be aroused to study alpha biofeedback in terms of brain alpha power through changing the tempo of music stimuli because music, as a media conveying information and emotion, might be more attractive than other stimuli.

5. Conclusions

This paper focuses on the relationship between EEGs and the effect of music tempo by analyzing the EEG spectra power in alpha band for different tempo music excerpts. Our results indicate that the alpha power decreases from original tempo data to middle bias tempo data and then to ultimate bias tempo data. These results show the feasibility of development of EEGs related to music tempo perception. As an effective media for conveying information and emotion, music has undoubted potential benefits, both in the research on physiology and psychology. Especially, in recent years, with the development of music therapy in clinic and brain-computer interface (BCI) in neuroscience,
research on the relationship between music and EEGs become more and more valuable. If we could modulate subjects’ alpha power by changing the tempo of music stimuli, and utilize this theory in clinical areas, such as music therapy, the applicant value is self-evident.

References


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