Analysis of Electroencephalogram and Pulse Waves during Music Listening

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Keywords: Scalp Electroencephalogram, Finger Plethysmogram, Largest Lyapunov Exponent, Parasympathetic Nerve.

Abstract: A tentative study is performed on the psychological effects of music based on the analysis of physiological indexes. We measured simultaneously the scalp electroencephalograms (EEG) and fingertip pulse waves for six healthy subjects before, during and after listening to music. The values of their low frequency (LF) and high frequency (HF) components of heart rate variability are obtained. By the method from chaos analysis, we calculated the largest Lyapunov exponents (LLE) of both scalp EEG and finger plethysmogram. Comparing the data of the resting condition and the music-listening condition, we observed significant tendencies over all subjects. We found that both values of LF and HF decreased, and so did the mean value taken over 14 EEG channels which were used for computation of LLE, whereas the distribution of the values tends to become average. Furthermore, it is notable that this averaging degree of LLE of scalp EEG generally accords with the decreasing rate of HF which reflects the activity of parasympathetic nerves.

1 INTRODUCTION

It is long believed that music has a certain impact on human mental performance. In recent years numerous studies have been carried out on exploring its psychological effect and therapeutic applications (Unkefer, 1990; McCraty et al., 1998; Schneck and Berger, 2006). However, just as what Schneck and Berger mentioned in their monograph, the existing music literature offers a bewildering array of unconnected ideas, thoughts, and theories.

Our attention is drawn to changes of certain physiological indexes that are caused by the behaviour of listening to music. A preceding work (Miao et al., 2011) has found that music yields a decrease in both the largest Lyapunov exponents (LLE) obtained from finger plethysmograms and those from the occipital and right cerebral areas of scalp electroencephalograms (EEG), which gave good agreement with the theoretical prediction obtained by a mathematical model they proposed.

The choice of the index LLE is justified, since it not only characterizes the exponential diverging rate of trajectories in chaotic systems according to its definition, but can serve as a significant indicator of “mental immunity” as discovered by recent studies (Imanishi and Oyama-Higa, 2006; Oyama-Higa and Miao, 2006; Oyama-Higa, Miao and Mizuno-Matsumoto, 2006; Hu et al, 2011). Specifically, mental health can be kept only if LLE fluctuate normally over time; continuously low or high values indicate low adaptability to external environment or excessive nervousness, respectively. This study still made use of this index.

In addition, since spectral analysis on heart rate variability is able to evaluate the activity of the autonomic nervous system, we took into account the high frequency (HF, 0.15-0.40 Hz) component,

Miao T., Oyama-Higa M., Kojima J., Suzuki T., Wang W. and Hu Y. (2012).
Analysis of Electroencephalogram and Pulse Waves during Music Listening.
In *Proceedings of the Sixth International Symposium on e-Health Services and Technologies and the Third International Conference on Green IT Solutions*, pages 31-35
DOI: 10.5220/0004473700310035

regarded as an index of parasympathetic nerve activity, and the low frequency (LF, 0.04-0.15 Hz) component, influenced by both sympathetic and parasympathetic nerves. A properly defined ratio "autonomic nerve balance (ANB)" was also considered.

To sum up, this tentative study is aimed at exhibiting and explaining the music effect in terms of changes in LF, HF and LLE of both finger plethysmogram and scalp EEG.

2 EXPERIMENT AND METHOD

2.1 Experiment Procedure

The subjects are healthy students from Osaka University in Japan. They include 5 males and 1 female (labelled with alphabets A to F), whose average age is 24.63 with a standard deviation of 2.45. Informed consent was obtained from all subjects. The place of the experiment is an examination room of Rakuwakai Otowa Hospital in Kyoto, Japan. The measuring instruments are a photoplethysmography sensor (Mini PGL, Model MPULSE-01) and a multi-channel EEG recorder (Neurofax EEG-1200, developed by Nihon Kohden Corporation) with 14 active electrodes.

We chose two famous Japanese songs for the subjects to listen to: *Jidai* (Time), a 1975 song by Miyuki Nakajima, and *Kawa no nagare no yō ni* (Like the Flow of the River), the last single recorded by decreased prominent enka singer Hibari Misora. Both are highly recognized songs, with well-crafted poetic lyrics and melodic gentle music.

The subjects were asked to lie down on a bed and keep their eyes closed during the whole process. When the instruments were ready and the subjects were relaxed, the first five-minute measurement began. Then the music was played through their headphones, while their pulse waves and EEG were taken for another five minutes. After listening to music, their resting condition was measured for the last five minutes.

2.2 Analysis Method

The method for estimating LLE taken from the subjects is the same with the recent work (Miao et al., 2011). The improved Rosenstein algorithm (Liu et al., 2005) was employed to reconstruct the phase space. The false nearest neighbour method gave the embedding dimensions $d = 4$ for time series of finger plethysmograms and $d = 8$ for that of scalp EEG. The first minimum of average mutual information (Fraser and Swinney, 1986) was applied to determine the time delay. We found the time delay being 50ms for both plethysmogram and EEG in the experiments.

LF and HF were obtained by the analysis software "Lyspect" (Oyama-Higa et al., 2012), developed by Chaos Technology Research Lab. The results are displayed in a panel (Figure 1), where the line graph at the bottom shows changes of LF (in red) and HF (in blue) over time. The autonomic nerve balance (ANB), shown in the right-side semicircular graph, is defined as a normalized value:

$$ANB = 10 \times \frac{LF}{HF + LF} \in [0, 10]. \quad (1)$$

Thus, $ANB < 5$ indicates predominance of parasympathetic nerve while $ANB > 5$ indicates sympathetic predominance.

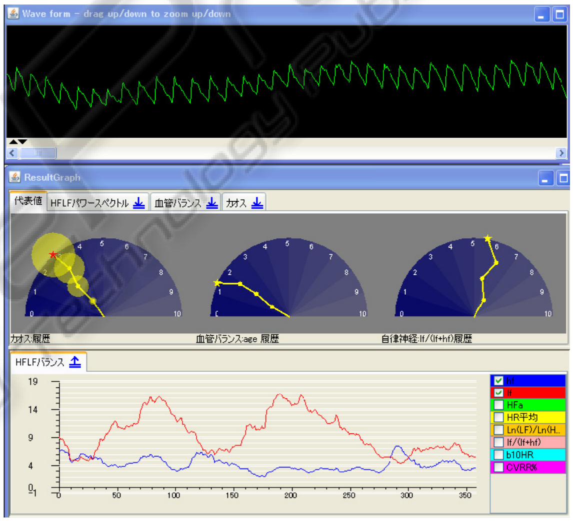

Figure 1: Lyspect analysis results.

3 ANALYSIS AND RESULT

3.1 LLE of Scalp EEG

Figure 2 shows the mean values of LLE over the 14 scalp EEG channels, obtained from the subjects during the three five-minute conditions: before, during and after listening to music.

The specific changes at each channel are displayed by topographical two-dimensional maps (Figure 3), in which deeply coloured area indicates a high value and vice versa.

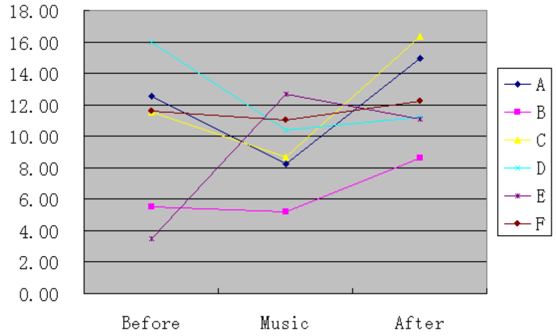

Figure 2: LLE of EEG: mean values taken over the 14 channels.

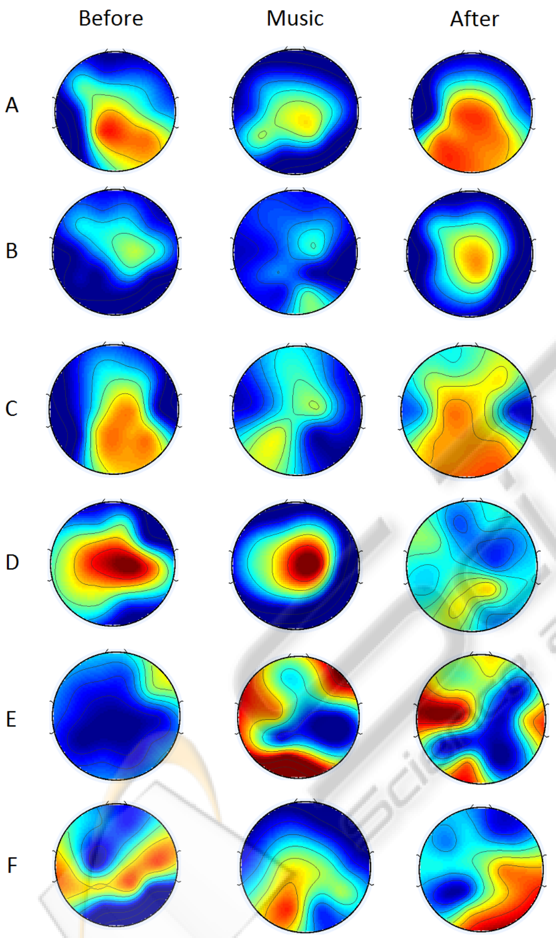

Figure 3: LLE of EEG: distribution at each of the 14 channels.

From Figure 2, we found in all subjects but Subject E a "decreasing then increasing" tendency in the mean of LLE taken over the EEG channels. Besides, what deserve more attention are the maps of Figure 3. We observed that, in all subject except Subject E, the distribution of LLE at EEG channels became average after they listened to music.

3.2 LLE of Finger Plethysmogram

Figure 4 exhibits LLE of finger plethysmogram, also taken from the conditions prior to, during and posterior to music listening, respectively.

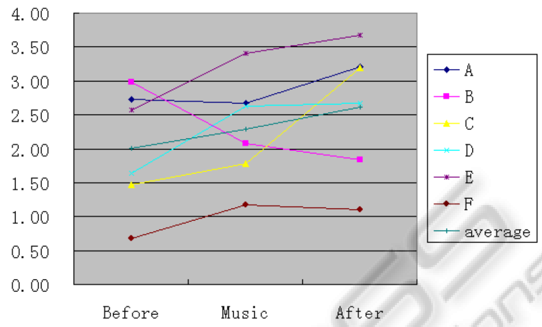

Figure 4: LLE of plethysmogram.

There exist both increasing (Subjects C, D, E and F) and decreasing (Subjects A and B) tendencies in the subjects. Moreover, the average LLE of plethysmogram over the 6 subjects increased after exposure to music. Therefore, in terms of changes in LLE of finger plethysmogram, this result does not correspond with our preceding study (Miao et al., 2011).

3.3 HF and LF

Changes in HF and LF throughout the three conditions are illustrated by Figure 5.

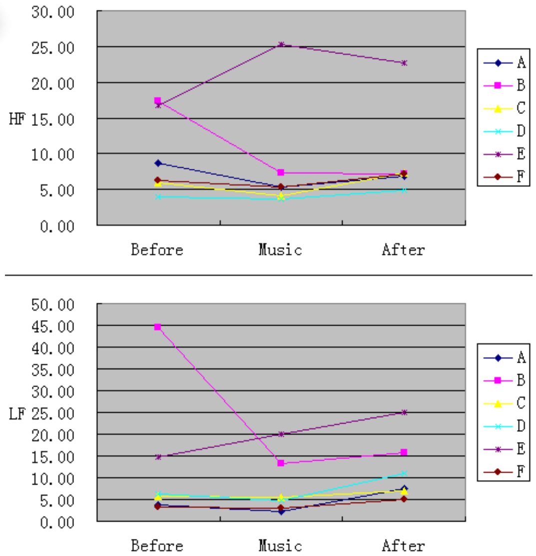

Figure 5: HF and LF

With the exception of Subject E, the main tendency is obvious: both values of their LF and HF decreased under the influence of music.

Moreover, together with Figure 3, a notable phenomenon is observed: the decreasing rate of HF from “Before” condition to “Music” condition is consistent, in general, with the degree of averaging in LLE of EEG under “Music” condition. Since the latter is represented by the standard deviation, a comparison is given in the following tables.

Table 1: Decreasing rate of HF and standard deviation of LLE of 14 EEG channels under “Music” condition.

Subjects	Decreasing rate of HF from "Before" to "Music"	Rank
A	39.77	2
B	58.25	1
C	31.72	3
D	7.31	5
E	-50.38	6
F	13.46	4
Subjects	Standard deviation of LLE of 14 EEG channels during "Music"	Inverse rank
A	27.31	2
B	17.22	1
C	28.62	3
D	34.55	4
E	42.17	6
F	36.39	5

3.4 ANB

Finally, we took into account changes of ANB, as shown in Figure 6.

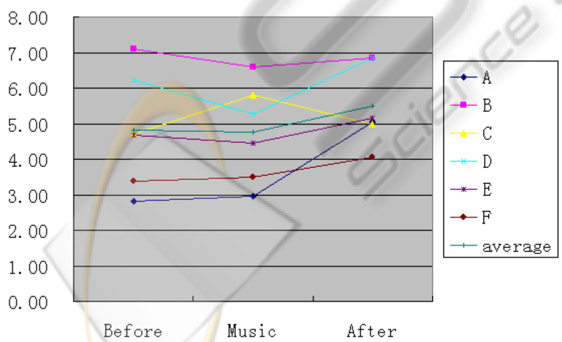

Figure 6: ANB

It can be observed that ANB of each subject was maintained near the balance value 5 throughout the three conditions, disregarding that for almost all of them the LF and HF experienced a decrease and then an increase.

4 CONCLUSIONS AND REMARK

This study observed changes in LLE of both scalp EEG and finger plethysmogram, as well as LF and HF components of heart rate variability. Several significant tendencies were found out in all subjects excluding one exception.

As a complement to our results, we discovered later that the same tendencies can still be observed in Subject E, who always served as an exception as stated above, if he listened to his favourite songs. In fact, according to an interview of the 6 subjects after the experiment on their feelings towards the two songs, Subject E harboured an antipathy, while the rest 5 subjects felt indifferent to or showed some appreciation for them.

We remark that not many studies in this field exist so far evolving the joint analysis of LLE of both EEG and plethysmogram. Furthermore, the consideration of LF and HF is what distinguishes this study from the previous work (Miao et al., 2011).

However, there still exist several limitations in this study. The changes in LLE of plethysmogram and ANB were not instrumental in the explanation, and analysis was not performed in terms of the LLE at each specific EEG channel. The underlying relationship between the music effect and the listener’s feeling towards the music is unclear. What is more, to test with only 6 subjects hardly sufficed to convince ourselves of the generality of the result. To overcome these limitations is a subject for future work.

ACKNOWLEDGEMENTS

The authors would like to express their sincere appreciation to Nihon Kohden Corporation for generously providing us with the measuring instrument.

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