# The EEG signals to consonance and dissonance tones

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The aim of this study was to investigate electroencephalogram (EEG) signals to the consonant and dissonant tones. In the first experiment, we used a paired-comparison method to find a relationship in perception between consonance and frequency deviation of tones. The results showed that the consonance characteristic forms the V-shaped curve that is consistent with previous studies. In the second experiment, we obtained a frequency-fluctuation of EEG. The results showed that the rhythmicity of frequency-fluctuation in alpha wave was steeper on the left frontal lobe in listening to dissonant tone than to consonant tone. In frequency-fluctuation in alpha wave the consonance characteristic formed the V-shaped curve that was similar to that obtained in psychological experiment. We found that the EEG signals varied according to the change in consonance, suggesting that the EEG signals could reflect psychological states.

***Key words:*** *sound, electroencephalogram (EEG), consonance, dissonance, frequency-fluctuation in alpha wave*

## Introduction

Many kinds of sounds in daily life give various influences to psychological aspects and brain activity.

For example, some dyad tones consisting of two components cause a feeling of consonant while others cause dissonant.

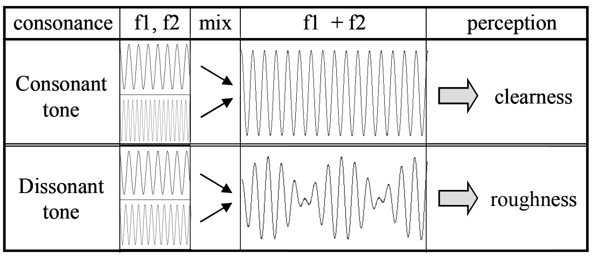


Fig.1 The waveform of consonant and dissonant tones.

The “consonant” tone, in general, was felt as a sensation of “clearness” or “euphonious” while the “dissonant” tone was felt as “turbidity” or “roughness.” According to the Helmholtz’s psychoacoustic theory, the perception of dissonance is characterized to the sensation of “beats” and “roughness” caused by interactions in the auditory periphery between adjacent partials of complex tones, while the perception of consonance is characterized by the relative absence of beats and roughness (Helmholtz, 1954).

As the frequencies of two components f1 and f2 separate, the consonance gradually decreases down to the most dissonant point, thereafter it monotonously increases and mostly recovers at an octave separation. Figure 2 shows a schematic diagram of the consonance characteristic as a function of frequency deviation of tones between f1 and f2. It forms a simple V-shaped curve when the degree of the consonance is plotted against an absolute difference in frequency of |f1-f2| for complex tone (Kameoka & Kuriyagawa, 1969).

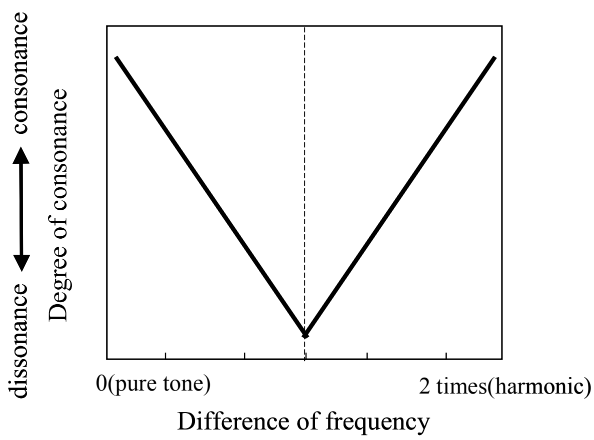


Fig.2 The V-shaped curve expected by change of consonance to frequency difference.

The consonance-dissonance relationship has been well investigated in acoustic psychology. In brain activity, on the other hand, the change in activity to consonant tone is poorly understood. The aim of this study was to investigate the cognitive process in the brain by measuring the EEG signals to the consonant and dissonant tones regarding.

We used a frequency-fluctuation in alpha wave of EEG signals to investigate the cognitive process in the brain. The frequency-fluctuation in alpha wave could be a good index to evaluate the cognitive state in the brain. The frequency-fluctuation could rhythmicically vary depending on the external environment. Recent studies have shown that a fluctuation of the heart rate and the frequency-fluctuation in alpha wave have been used for clinical diagnosis and the mental indicator (Yoshida, 1998).

In the previous studies, as the relation between in alpha wave characterized to fluctuation of biosignal, the slope of the curve of the frequency-fluctuation in alpha wave was the steepest at around 1 kHz and decreasing away from it (Nuruki, Ueno, Tsujimura & Yunokuchi, 2004). It means that the frequency-fluctuation in alpha wave characterized to frequency change to pure tones. Thus, we could expect that the change in frequency-fluctuation in alpha wave vary to consonance of complex tones.

## Methods

Subject: Seven healthy volunteers participated in the experiment (three male and four female, 21-24 years old, mean age 22.4 years). All of them had normal hearing checked by the pure-tone audiometry. They gave informed consent before the experiment.

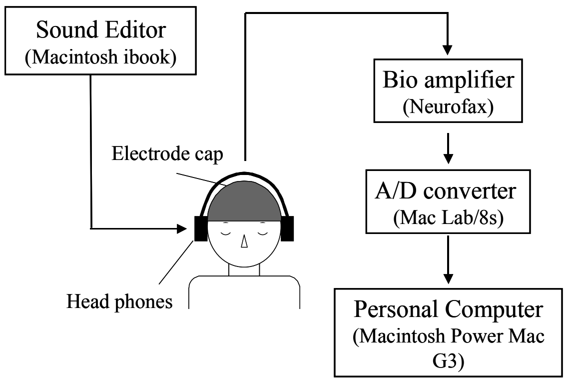


Fig.3 A schematic diagram of the EEG recording.

Auditory stimulation: We used nine different kinds of complex tones for the auditory stimulation. Each of complex tone consisted of a mixture of two pure tones, the primary component, f1 and the secondary component, f2. The frequency of f1 was fixed at 440 Hz, and nine frequencies were used for f2 that were 444, 448,462, 481, 528, 572, 660, 770 and 880 Hz. Auditory stimulations were randomly presented for 30 seconds to both ears through the headphones (Victor HP-310) from personal computer (Macintosh ibook). The A-weighted sound pressure level for each stimulus was 63dB. We would expect to extract cortical responses since the intensity of the stimuli were the same A-weight sound pressure level such that we compensated the gain loss at the early site of auditory pathway (Nuruki, Ueno, Tsujimura & Yunokuchi, 2004).

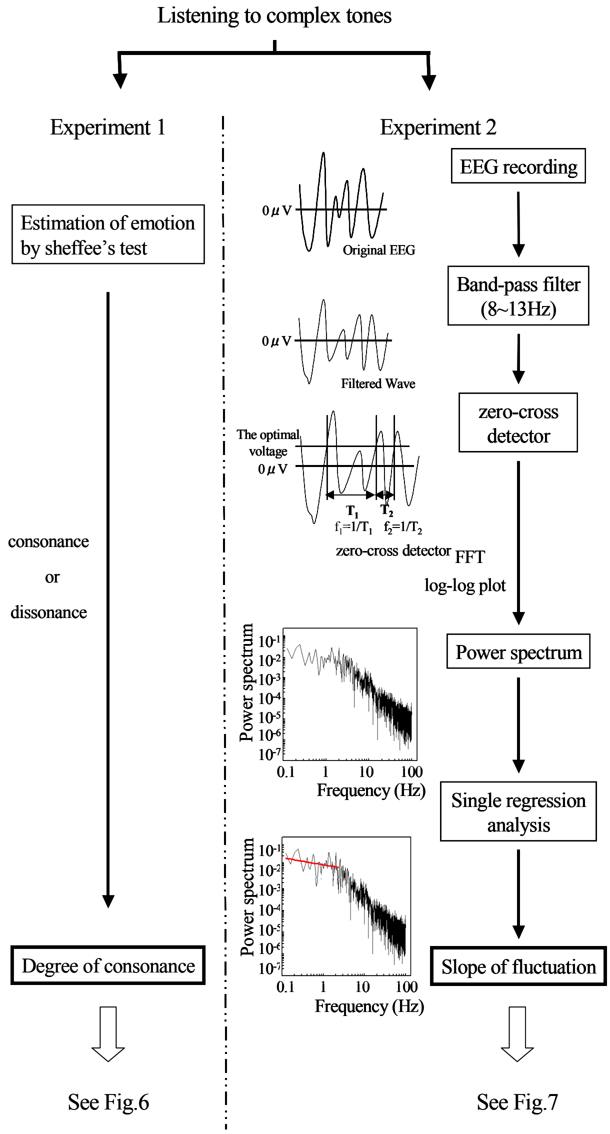


Fig.4 The flow chart of experiment and analysis.

EEG recording: The EEG signals with the linked-ear reference were recorded from 8-electrodes positioned according to the international 10-20 system that were Fp1, Fp2, C3, C4, T3, T4, O1 and O2 using the standardized Erectro-Cap device (Nihon Kohden, Erectro-cap). We checked that impedances of all electrodes were less than 5 kΩ throughout. A schematic diagram of the EEG recordings is shown in Figure 3. The

EEG signals were amplified by 0.5 to 60 Hz with the band-pass filter, and download it to the personal computer (Macintosh Power Mac G3) by the sampling frequency of 2 kHz through the A/D converter (AD Instruments, Mac Lab/8s, 12bits).

Analysis: We calculated the frequency-fluctuation of the alpha wave from the EEG signals in the following. A procedure was shown in Figure 4. First, the alpha wave components were extracted from EEG signals with the band-pass filter between 8 and 13Hz. Second, the frequency of the alpha wave was calculated by a zero-cross detector (Nuruki & Ueno & Tsujimura & Yunokuchi, 2004). The frequency-fluctuation of the alpha wave was calculated from the frequency of the alpha wave by the fast Fourier transform (FFT). We obtained the slope of frequency-fluctuation in alpha wave by fitting a line to points at low frequencies. The slope of spectrum could be divided into the domain of low frequency and the domain of high frequency bordering on the inflection point, and the present study was observed in the low frequency domain.

Psychological experiment: For scaling consonance values from various kinds of tones, paired comparison method (Sheffe's test) was adopted. Subjects listened to two tones, A and B, successively presented through headphones for 4.0 seconds each with 0.5 seconds of silence. They compared the second tone, B, with the first, A, and assigned one of the following 7 numbers from –3 to 3 according to the subjective distance in consonance between A and B. Figure 5 shows the scale of number. If A was more dissonant than B, a minus sign and if more consonant, a plus sign was given.

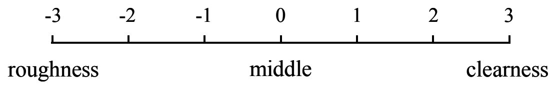


Fig.5 The estimation scale of Sheffe's test.

## Results

Figure 6 shows the degree of the consonance as a function of frequency deviation of tones. The vertical axis shows the degree of slope of power spectrum of frequency-fluctuation in alpha wave and the horizontal axis shows the frequency deviation of tones. The horizontal axis represents a frequency deviation of tones between stimulus frequencies of f1 and f2 that is given by 100(f2-f1)/f1 in a logarithmic scale. For example, if it is f1=440 and f2=528, the frequency deviation of tones is 20.

Figure 7 shows the degree of slope of power spectrum of frequency-fluctuation in alpha wave as a function of frequency deviation of tones. The vertical axis shows the degree of slope of power spectrum of frequency-fluctuation in alpha wave and the horizontal axis shows the frequency deviation of tones. The value was the average from 7 subjects.

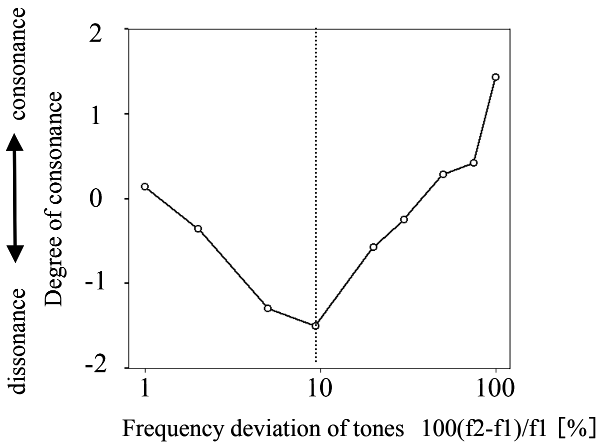


Fig.6 The relationship in perception between consonance and frequency deviation of tones.

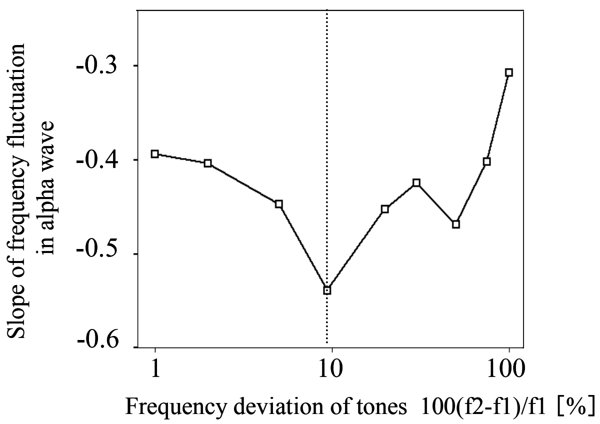


Fig.7 The slope of frequency-fluctuation in alpha wave when subjects listened to complex tones.

As shown in Figure 6, the consonance characteristic to frequency deviation of tones formed V-shaped curve that is consistent with previous study (Kameoka & Kuriyagawa, 1969). As shown in Figure 7, the slope of frequency-fluctuation in alpha wave was steeper in listening to dissonant tone than to consonant tone.

Figure 8 shows the correlation between the slope of frequency-fluctuation in alpha wave obtained from EEG signals and the degree of consonance obtained by psychophysical test. The vertical axis shows the degree of slope of frequency-fluctuation in alpha wave and the horizontal axis shows the degree of consonance. The correlation coefficient was 0.82 ($p<0.05$) investigated using Peason's correlation coefficient test. The frequency-fluctuation in alpha wave associated with consonance.

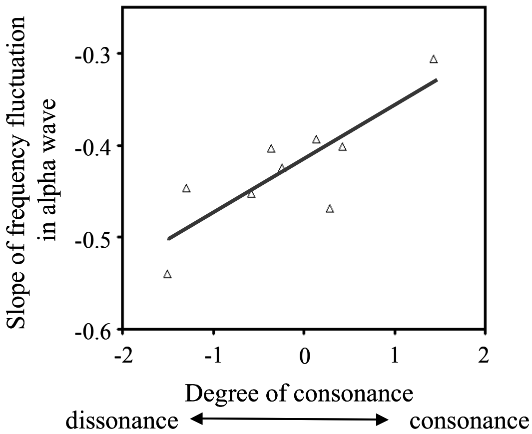


Fig.8 The correlation of the slope of frequency-fluctuation in alpha wave and consonance.

## Discussion

The result showed that the slope of the curve of frequency-fluctuation in alpha wave was steeper in listening to dissonant tone than to consonant tone. We suggested that the frequency-fluctuation in alpha wave was associated with consonance when subject listened to complex tone. As to these results, we put forward two hypotheses as follows.

First, the consonant tone causes a feeling of clearness while the dissonant tone causes a feeling of roughness. Psychological states also varied with change of consonance. Change in frequency-fluctuation in alpha wave varied depending on the change in consonance, suggesting that the frequency-fluctuation reflect psychological states.

Second, frequency-fluctuation in alpha wave shows the rhythmicity of a signal. The rhythmical signal like sine wave has the steep slope of the curve of frequency-fluctuation, while the nonrhythmical signal like white noise has the low slope of frequency-fluctuation. These phenomena have been reported in previous study (Yoshida, 1998). In addition, the previous physiological studies reported that neuronal responses evoked by dissonant tones display oscillation synchronized to the beat of different frequency of complex tones, whereas neuronal responses evoked by consonant tones display little or no synchronized activity (Fishman, 2001).

Therefore, we suggest that the activity of neuron have rhythmicity by listening to dissonant tones, and that EEG signals reflect those rhythmicity.

## Conclusion

In the present study, the aim was to clarify frequency-fluctuation changes in alpha wave to the consonant and dissonant tones regarding the cognitive process, and had experiment. The result showed that the slope of frequency-fluctuation in alpha wave was steeper on the left frontal lobe in listening to dissonant tone than to consonant tone. In the change in frequency-fluctuation in alpha wave the consonance characteristic forms V-shaped curve that is similar to that obtained in psychological experiment. We found that the change in frequency-fluctuation of EEG signals varied according to the change in consonance, suggesting that the EEG signals of frequency-fluctuation could reflect psychological states.

## References


Helmholtz, H. (1954). On the Sensations of Tone as a Physiological Basis for the Theory of Music. *Translated by A.J. Ellis, Dover*, 179.

Kameoka, A. & Kuriyagawa, M. (1969). Consonance Theory Part I :Consonance of Dyads. *The Journal of the Acoustical Society of America*, **45**, 1451-1459.

Fishman, I.Y. (2001). Consonance and Dissonance of Musical Chords: Neural Correlates in Auditory Cortex of Monkeys and Humans. *The American Physiological Society*, **86**, 2761-2788.

Blood, A. & Zatorre, R., (1999). Emotional responses to pleasant and unpleasant music correlate with activity in paralimbic brain regions. *Nature neruroscience*, **2**, 382-387.

Nuruki, A., Ueno, Y., Tsujimura, S., & Kazutomo, Y. (2004). Response of Electroencephalogram to Pure Tones Corrected by A-weighted Sound Pressure Level. *Bio Medical Engineering,* **42**, 54-55.

Yoshida, T. (1998). The estimation of mental stress by 1/f frequency fluctuation of EEG. *Brain Topography Today*, 762-767.