Investigation of psychological and neurophysiological aspects to pure tones

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We investigated the psychological and neurophysiological aspects to pure tones. The loudness of pure tones are determined by A-weighted sound pressure level, which could compensates the effect at the early site, for test stimuli to isolate the effects occurred at the latter cognitive level. First, we conducted a psychological experiment to measure a level of preference to pure tones using a paired-comparison method. The most preference pure tone obtained from a paired-comparison method (Scheffe's method) was around 0.4 to 2 kHz and the amount of the preference decreased as the frequency of the pure tone increased/decreased, indicating that the relationship between the preference and the frequency of the pure tone forms U-shaped function. In the second experiment, we measured the EEG signals responding to pure tones. To estimate the level of comfort we calculated an alpha-wave fluctuation from the EEG signals. The results showed that the slope of the alpha-wave fluctuation had a peak at 1 kHz and decreased away from 1 kHz as the frequency of pure tone increased/decreased, indicating that the relationship between the comfort and the frequency of pure tones forms U-shaped function. The results of two experiments indicate that the alpha-wave fluctuation of the EEG signals could reflect the psychological aspects responding to pure tones.

Key words: *Pure tone, A paired-comparison method, Alpha-wave fluctuation*

Introduction

In a sense of hearing, several studies have revealed the relationship between sounds and the brain activities. In these studies the brain activities were affected both in the sensation level at the early site of the pathway and at the latter cognitive level. It is widely accepted that the perception of pure tone is mostly determined at the early site of the auditory pathway as an equal-loudness curve (Robinson, D.W. & Dadson, R.S, 1957). Although many studies have shown the relationship between sound (music, environmental noise, white noise and so on) and brain activity (Christina M. at all, 1999, Yagi, R. et al, 2003), few studies measured the brain activities regarding the cognitive process. These studies included the effects at the early site of the pathway. In order to reduce the effects at the early site, we used pure tones corrected by the same A-weighted sound pressure level at several frequencies as sound stimulation. The correction of the amplitude with A-weighted sound pressure level allows us to isolate the effects occured at the latter cognitive site from those at early site, since the A-weighted sound pressure level compensates for the sound pressure loss at the early site.

In this study we investigated the psychological and neurophysiological aspects to pure tones. The loudness of pure tones are determined by A-weighted sound pressure level, which could compensates the effect at the early site, for test stimuli to isolate the effects occurred at the latter cognitive level. The interaction of pure tones with the latter cognitive site may reflect changes in psychological behavior and in brain electrical activity recorded by the electroencephalogram (EEG). It is well known that neural activities in the brain are strongly associated with psychological aspects. It is reported that 1/f frequency fluctuation of EEG signals are a useful index to estimate mood and anxiety in mental stress states (Yoshida, T., 1998), and that alpha power of EEG signals show the state of arousal.

The aim of this study is to clarify the effect of frequency of pure tones. We used a paired-comparison method to estimate the psychological behavior and used the alpha wave fluctuation to estimate the neurophysiological aspect.

Methods

Fourteen volunteers with normal hearing ability (age 21-25 years) participated. Informed consent was obtained from all volunteers. We produced two types of experiment, psychological and neurophysiological experiment. Subjects were seated on a comfortable chair with eye close and took an enough rest between each session. For the auditory stimulation, twelve pure tones, 30, 60, 100, 200, 400, 700, 1k, 2k, 4k, 5k, 8k and 10k (Hz) were used at 73 dB of A-weighted sound pressure level.

First, we conducted a psychophysical experiment to measure a level of preference to pure tones for six subjects. Scheffe's method of paired comparison was used to evaluate the preference of pure tones (The five grades of evaluation are –2, –1, 0, 1 and 2.). Each of paired auditory stimulation was randomly presented binaurally, through the headphone for 1 second in duration.

In the second experiment, we measured the EEG signals responding to pure tones. To estimate the level of comfort we calculated an alpha-wave fluctuation from the EEG signals. EEG signals were recorded with linked-ear reference from Fp1 and Fp2 of the 10-20 International System of electrode placement. Electrode impedances were all under 5 kohms. The EEG signals were amplified by a band-pass of 0.5-60 Hz, with the 60-Hz notch filter in and digitized at the sampling rate of 2 kHz.

The power spectrum of the EEG at each electrode was calculated by Fast Fourier Transform algorithm. Then, alpha wave fluctuation was calculated from the slope of the fluctuation spectrum, obtained from Fp1 and Fp2 electrodes. Figure 1 shows the block diagram of the analyzing procedure for frequency fluctuation in alpha wave. It was reported that the spectral pattern of frequency fluctuations in this band had a significant correlation with changes in mood and subjective arousal level (Yoshida, T., 1998). At first, the recorded EEG is passed through the band-pass filter and alpha wave component is extracted from each channel. Next, generating serially a pulse at a given threshold point in the up going slope of the filtered wave with an electric circuit, onset times of pulses are recorded on a computer disk to transform alpha wave cycles into the time series of pulse.

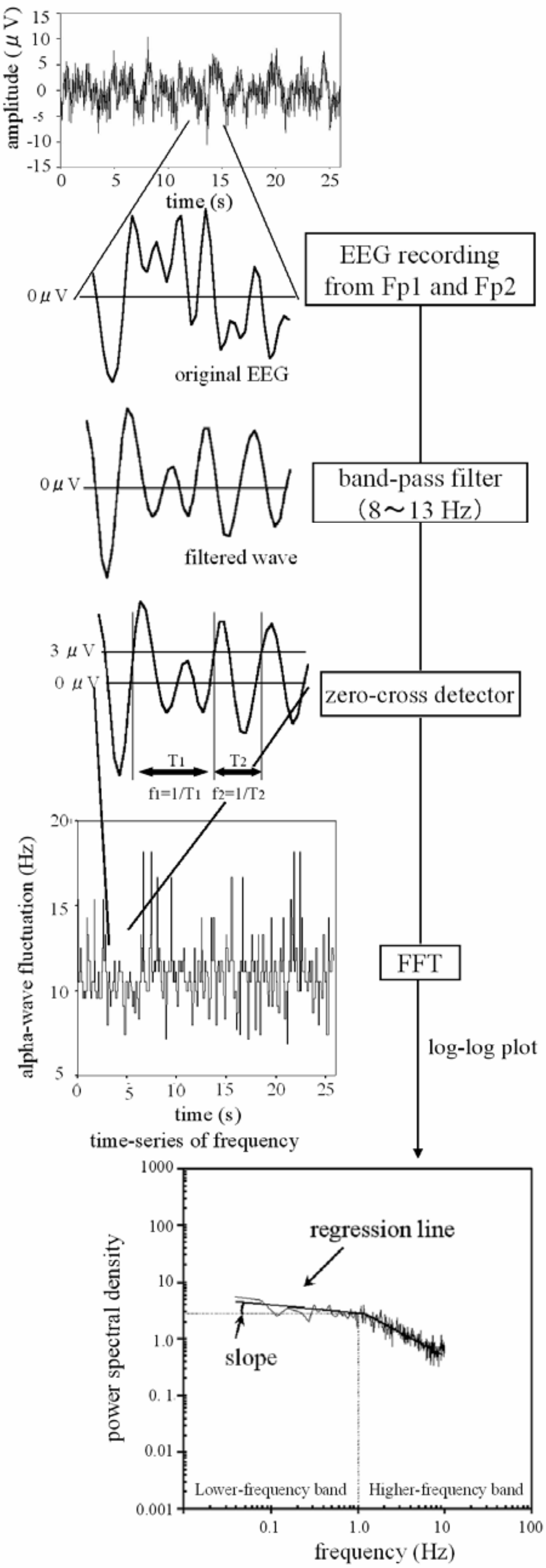

Figure 1: Block diagram of the analyzing procedure for frequency fluctuation in alpha wave.

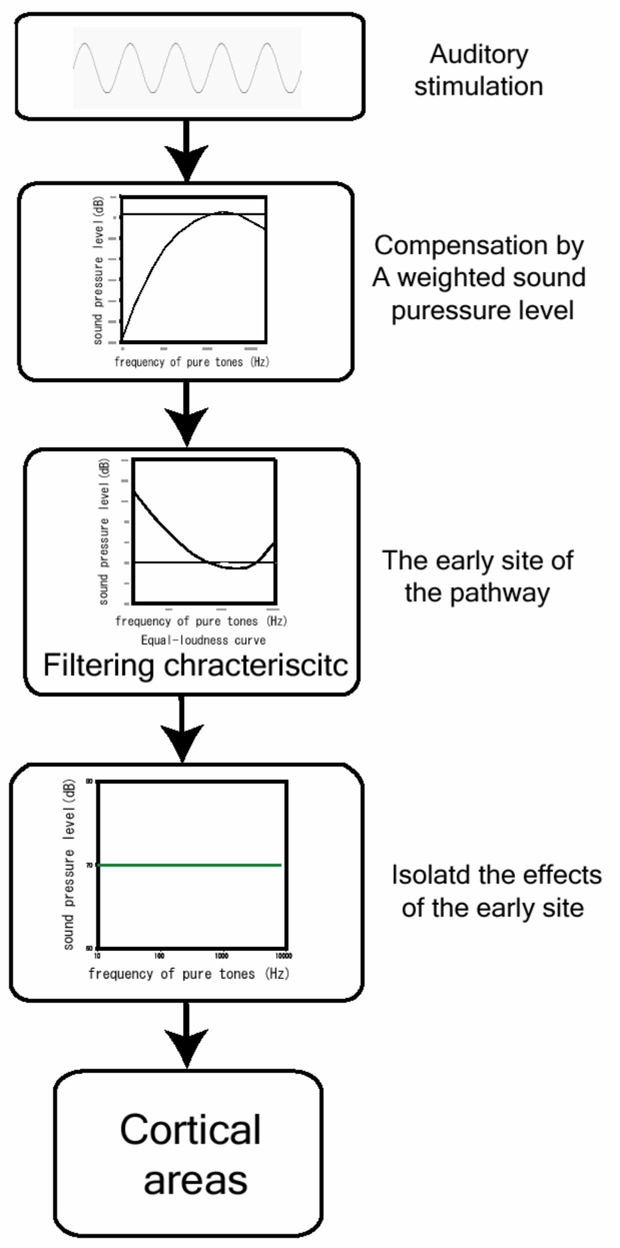

Figure 2: A schematic diagram for compensation of a sound pressure loss at the early site of the auditory pathway. Since these temporal patterns are filtered by equal-loudness curve at the early site of the pathway and goes to cortex, cortical activities include the effect at the early site of the auditory pathway. In order to isolate the effects of complex temporal patterns at the cortex from those at the early site of the pathway, it is essential to compensate a sound pressure loss at the early site of the auditory pathway.

The frequency fluctuation is expressed by the relation between this time series on the vertical axis and the passage of time on the horizontal axis. In the process of post analysis, the characteristic of fluctuation is examined using the spectrum method. Auditory stimulation was presented binaurally, through the headphone. Auditory stimulation was 30 seconds in duration and performed randomly. Figure 2 shows a schematic diagram for compensation of sound pressure loss at the early site of the auditory pathway.

Results & Discussion

Figure 3 shows the level of preference as a function of frequency of pure tones. Results showed that the slope varied depending on the frequency of pure tones and formed a U-shaped curve as a function of frequency of pure tones. The most preferred pure tone obtained from a paired-comparison method was around 0.4 to 2 kHz and the amount of the preference decreased when the frequency of the pure tone was away from the peak.

In most of the subjects, it formed the U-shaped curve as a function of frequency of pure tones in a similar way. The trough of the curve was around 1-2 kHz and close to zero as frequency increases/decreases.

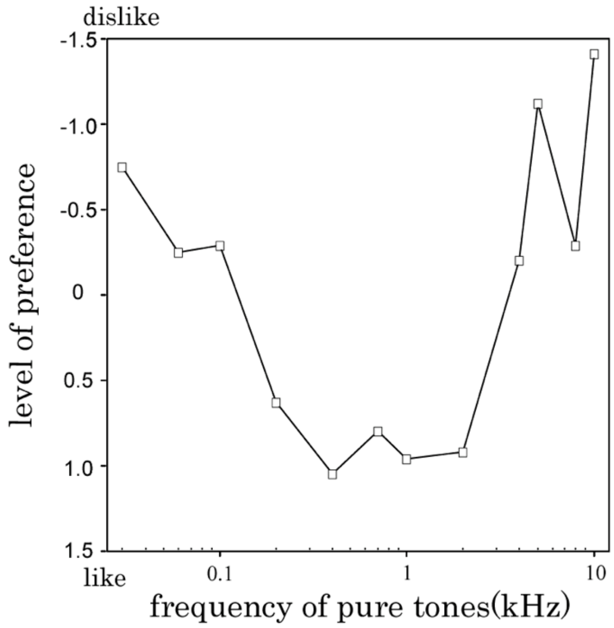

Figure 3: The level of preference as a function of frequency of pure tones.

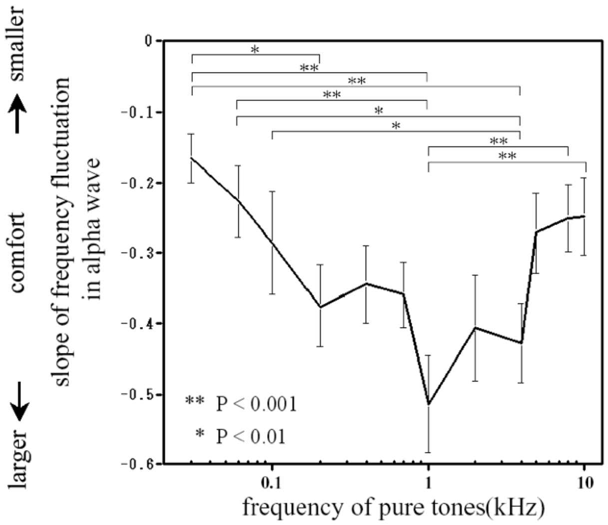

Figure 4: Slope of frequency fluctuation in alpha wave as a function of frequency of pure tones on Fp1.

We measured EEG signals to pure tones that have the A-weighted sound pressure level (73 dB) at several frequencies. We calculated the alpha wave fluctuation from these signals. Figure 4 shows the slope of frequency fluctuation in alpha wave on Fp1. As shown in figures 3 and 4, they had a similar U-shaped curve. To find a correlation between psychological aspect (Fig. 3) and neurophysiological aspect (Fig. 4) we plotted the slope of frequency fluctuation as a function of preference scale (Fig. 5). Figure 5 shows a good correlation of the preference scale against the slope of the frequency fluctuation (r=-0.71, p<0.001).

These results suggested that pure tones around 0.4 to 2 kHz could induce a brain activitiy regarding as a comfortable feeling. In other words, people feel comfortable when hearing these pure tones.

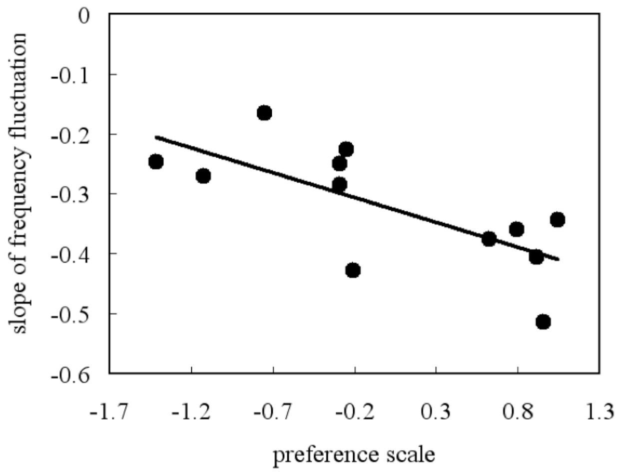

Figure 5: Relationship between slope of frequency fluctuation and preference scale.

Conclusion

The psychological aspect and brain activity varied depending on the frequency of pure tones and formed the U-shaped curve. The results of two experiments indicated that the alpha-wave fluctuation of the EEG signals could reflect the psychological aspect responding to pure tones.

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