The presence of noise during the performance of cognitive tasks involving such as memory, commonly causes a subjective experience of annoyance, which can lead to a decline in performance. This tendency is stronger in response to meaningful noise, such as music and conversation, than for meaningless noise, such as the sound of traffic, and heating ventilating and air-conditioning noise. In designing a comfortable sound environment, it is important to understand the relationship between not only the measurable aspects of noise, such as the sound pressure level, but also the qualitative aspects, such as the degree of meaningfulness of the noise, and the subjective experience of annoyance. On the other hand, it is well known that the transient event-related potentials (ERPs) in the brain wave elicited by internal or external stimuli are related to the operation of selective attention. In this study, the effects of meaningfulness of the external noise on selective attention during mental task were considered by psychophysiological experiment. First, we examined differences in the Global Field Power (GFP) for ERPs during the auditory odd-ball paradigms under the meaningful noise or meaningless noise. In addition, the principal component analysis (PCA) was adopted to define a set of components on P300 GFP.

Keywords: Meaningful noise, Meaningless noise, Selective attention, Odd-ball paradigm, Event-related potentials, Global field power.

1. Introduction

To create a comfortable sound environment in which cognitive tasks are performed, it is important to understand the relationships between the acoustic characteristics of external noise and psychophysiological evaluation of the noise. When carrying out intellectual activities involving memory or arithmetic tasks, it is common for external noise to increase levels of subjective annoyance, which can lead to a decline in performance. This tendency is stronger in response to meaningful noise, such as music and conversation, than for meaningless noise, such as the sound of traffic, and heating, ventilating and air-conditioning noise. Hence, in designing a comfortable sound environment, it is important to understand the relationship between not only the measurable aspects of external noise, such as the sound pressure level, but also the qualitative aspects, such as the degree of meaningfulness of the external noise, and the subjective experience of annoyance. On the other hand, it is well known that the transient event-related potentials (ERPs) elicited by internal or external stimuli in the brain wave are related to the operation of selective attention [1]. In this study, the effects of meaningfulness of the external noise on selective
attention during mental task were considered by psychophysiological experiment. First, we examined differences in the Global Field Power (GFP) \([2][3]\) for ERPs during the auditory odd-ball paradigms under the meaningful noise or meaningless noise. In addition, the principal component analysis (PCA) \([4]\) was adopted to define a set of components on P300 GFP.

2. Outline of experiment

Psychophysiological experiments were conducted to determine the effects of the meaningfulness of external noise on selective attention to auditory stimuli by examining differences in brain ERPs during the completion of the repetitive odd-ball paradigm. The outline of the experiments was as follows.

2.1 Participants

A total of 8 students with normal hearing participated in the experiment.

2.2 Odd-ball paradigm

The odd-ball paradigm is typically used to examine selective attention and information processing capacity \([1]\). In this task, subjects detect and respond to rare target events embedded in a series of repetitive events. Thus, to complete the odd-ball task it is necessary to regulate attention to a stimulus. In the auditory odd-ball paradigm, the common non-target stimulus (“frequent”) was a 1,000 [Hz] tone burst. The target stimulus was 2,000 [Hz] tone burst (“rare”) with an occurrence probability of 20 [%]. Both stimuli were presented binaurally at 60 [dB], and 120 [ms] duration (including 10 [ms] rise-fall time and 100 [ms] plateau). The frequent-rare sequence was randomly presented with an inter-stimulus interval of 2 [s]. The subjects task was only to count the “rare” stimuli for approximately 10 [min].

2.3 External noise

The following external noises with different degree of meaningfulness, were employed as examples of typical indoor noises.

(a) Meaningless noise

Pseudo voice-noise from a CD that was originally produced for the evaluation and fitting of hearing aids (TY-89) \([5]\) was used as meaningless noise.

(b) Meaningful noise 1

Multi-talker noise from a CD for the evaluation and fitting of hearing aids (TY-89) \([5]\), was used as meaningful noise 1.

(c) Meaningful noise 2

Male speech, produced by deleting handclaps, sound effects, and music, etc. from commercially available speech Tapes, was used as meaningful noise 2.

For practical reasons, the energy-mean value of the sound pressure level of the above external noises was adjusted to approximately 50 [dB]. In addition, the following conditions were tested.

For practicably reasons, the energy-mean value of the sound pressure level of the above external noises was adjusted to approximately 50 [dB]. In addition, the following conditions were tested.
Participants were seated in a sound-attenuated electrically shielded room. The auditory signal was generated by a CD player and presented through loud-speaker. Electroencephalogram (EEG) was recorded from 20 locations (Fp1, Fpz, Fp2, F7, F3, Fz, F4, F8, T3, C3, Cz, C4, T4, T5, P3, Pz, P4, T6, O1, O2) of scalp based on 10-20 system with Ag/Ag Cl electrodes of which impedance was held below 10 kΩ. Electrodes were referenced to linked earlobes, and the ground electrode was placed on the midforehead electrode (Fpz). The electrooculogram (EOG) was recorded from an electrode located at the supra-orbital ridge of the right eye and referenced to the linked earlobes. EEG and EOG signals were amplified with a...
bandpass filter of 0.01 to 30 [Hz], and recorded with 16-bit quantization level at sampling rate of 1 [kHz], continuously. ERPs for the responses to the “rare” and “frequent” stimuli were synchronously averaged to enhance the evoked signal and suppress the background brain activity.

3. Effect of meaningfulness of the external noise

3.1 Global field power

It is well established that ERPs elicited by internal or external stimuli, can be measured using EEG[6]. A waveform of ERPs after stimulus-triggered averaging to auditory “frequent” and “rare” stimuli, was individually calculated on the each electrode position under the each external noise condition. The Global
Field Power (GFP) \([2][3]\) is proposed as method to identify peaks and latency of evoked ERPs components of multichannel recordings. GFP which is defined as the spatial root mean squared across all electrodes, is given by

\[
GFP = \left[ \frac{1}{N} \sum_{i=1}^{N} (u_i - \bar{u}) \right]^{1/2}
\]

(1)

where \(N\) is the number of electrodes which measure the observed voltages \(u_i\) at electrode \(i\), \(\bar{u}\) is averaged reference of \(u_i\). GFP which is reference-independent, has the advantage of providing a spatially unbiased measure of the electric field strength at the scalp. By use of GFP measure, the electric signal amplitude are estimated at each time point despite slight variations of individual peak latencies across different electrode positions. GFP were individually calculated at each time point from ERPs of 19 electrode positions under the each external noise condition. Figs 1, 2, 3 and 4, show mean and standard deviation on GFP across subjects under the noise condition (a), (b), (c) and (d). In the case of no external noise (Fig 4), there is a positive peak occurring around from 300 to 400 ms after presentation of stimuli. A so-called 300 component is thought to reflect the resolution of uncertainty or the perceptual decision that an expected signal has occurred. These components are related to selective attention and working memory. On the contrary, the P300 component is unclear under the meaningful noise 2 (Fig 3). We found reliable differences in the P300 ERPs between the external noise condition. These results indicate that attention to the “rare” stimulus was influenced by the degree of meaningfulness of the external noise during completion of auditory cognitive tasks.

### 3.2 Principal component analysis for event-related potentials

Techniques such as principal component analysis (PCA)[6] use correlational structure of an GFP data set to define a set of components. For each 32 wave forms of GFP after stimulus-triggered averaging to auditory “rare” stimuli (external noise condition: \(4 \times \) subjects: 8), voltages from 0 ms to 500 ms, were averaged for 20 ms. 800 (\(32 \times 25\)) data sets were employed for PCA. Based on Minimum Average Partial test (MAP) [7] for determining the number of factors to retain in PCA, 8 principal components were extracted. Factor loadings of 8 principal components were shown in Fig 5. It was assumed that
principal component I, which has the largest eigenvalue, was associated with P300 component. Figure 6 shows averaged value and standard deviation of score of principal component I for each external noise condition. In Fig 6, scores of principal component I under meaningful noise 2 was smaller than other external noise conditions. To investigate whether the differences in scores of principal component I were significant, we conducted the factor repeated-measure analysis of variance (ANOVA) with the external noise condition [meaningless noise, meaningful noise 1, meaningful noise 2, no external noise]. There were significant main effect of the external noise condition on scores of principal component I ($p < .01$). Also, a post-hoc multiple comparison (Fisher’s LSD test) was also used. We found statistically reliable differences in the score of principal component I between (c) and (d) external noise condition in Figure 6 ($p < .01$). Thus, P300 ERPs components related with selective attention to auditory cognitive tasks, was influenced by the degree of meaningfulness of the external noise.

4. Conclusion

This study focused on the effects of the meaningfulness of external noise. We examined the effects of meaningful noise and meaningless noise on physiological activity while carrying out auditory cognitive tasks. Specifically, the P300 components of the ERPs elicited by the auditory odd-ball paradigms, were measured using EEG. The electrophysiological results revealed significant differences of the GFP on P300 component between meaningful and no external noise. In addition, the principal component analysis (PCA) was adopted to define a set of components on the GFP. Our results extract 8 principal components associated with latent component of ERPs during the completion of repetitive auditory oddball paradigm under the meaningful noise and no external. The results revealed that the degree of meaningfulness of the external noise had a strong influence on selective attention to auditory stimuli in cognitive tasks. In conclusion, in designing comfortable sound environments in spaces used for cognitive tasks, it is appropriate to consider not only the sound pressure level, but also meaningfulness of the external noise that is likely to be present.

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