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A study on physiopsychological evaluation of noise during mental memory tasks

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ABSTRACT

The presence of noise during the performance of cognitive tasks involving memory or arithmetic, commonly causes a subjective experience of annoyance, which can lead to a decline in performance. This tendency is stronger for meaningful noise such as music and conversation than for meaningless noise such as road traffic noise. This paper describes the psychophysiological effects of meaningful noise. Specifically, we first focus on the degree of meaningfulness of noise, then discuss how the brain responds during cognitive tasks. Transient event-related potentials (ERPs), elicited by internal or external stimuli, can be measured using electroencephalography (EEG). The peak amplitude and latency of P300 and N100 components are related to the operation of selective attention The present experiment was designed to determine the effects of meaningfulness of the noise on selective attention to auditory target stimuli in an odd-ball paradigm and a repetitive probe-digit task. To this end, we examined differences in the peak amplitude of these components. In addition, we considered whether relationships between the characteristics of ERPs, the subjective experience of annoyance in response to the noise, and performance were correlated with a measurable index, such as the percentage of correct answers or reaction time. Our results suggested that whether noise is meaningless or meaningful has a strong influence on selective attention to stimuli in cognitive tasks, which is related to the subjective experience of annoyance, and to task performance.

INTRODUCTION

To create a comfortable sound environment in which cognitive tasks are performed, it is important to understand the relationships between the characteristics of external acoustic noise and psychophysiological evaluation. When carrying out intellectual activities involving memory or arithmetic tasks, it is common for 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 (Saeki et al. 2003) (Tamesue et al. 2007). Hence, 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. This paper describes the psychophysiological effects of meaningful noise. Specifically, we used noise types of varying degrees of meaningfulness to test the effects of noise on transient event-related potentials (ERPs) related to selective attention (S.Sutton et al. 1965) and working memory operations (Waugh and Norman 1965), during cognitive tasks.

To this end, we measured the effects of meaningfulness of noise on selective attention to auditory target stimuli in the odd-ball paradigm (S.Sutton et al. 1965) and repetitive probe-digit task (Miller 1956) by examining differences in peak amplitudes of the N100 or P300 ERP components (Cacioppo et al. 2000). In addition, we considered whether the relationships between the characteristics of ERPs, levels of annoyance in response to the noise, and task performance correlated to a measurable index such as the percentage of correct answers or reaction time. The results suggested that whether the noise was meaningless or meaningful has a great influence on selective attention to stimuli in cognitive tasks, which is related to the experience of annoyance and task performance.

It should be noted that the results presented here were obtained under the conditions described below.

A. Subjects in the psychophysiological experiment were male and female students aged in their twenties, with normal hearing.
B. Subjects performed two cognitive tasks: a selective attention task and a simple short-term memory task.

OUTLINE OF PSYCHOPHYSIOLOGICAL EXPERIMENTS

Psychophysiological experiments were conducted to determine the effects of the meaningfulness of noise on selective attention and working memory functioning by examining differences in brain ERPs during the completion of repetitive cognitive tasks. In addition, we tested whether the level of annoyance in response to noise and task performance was correlated to a quantitative index, such as the percentage of correct answers or reaction time change during the completion of probe-digit tasks under the influence of meaningful noise. The outline of the psychophysiological experiments was as follows.

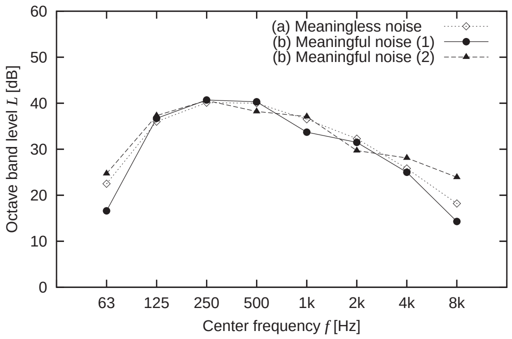


Figure 1: Octave band levels of noise

Subjects

A total of nine students (seven male and two female) with normal hearing participated in the psychophysiological experiment.

External noise

The following 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) (Yonemoto 1995) was used as meaningless noise.

(b) Meaningful noise

(b-1) Male and female speech, produced by deleting handclaps, sound effects, and music, etc. from commercially available speech CDs, was used as meaningful noise.

(b-2) Multi-talker noise from a CD for the evaluation and fitting of hearing aids (TY-89), was used.

The octave band levels of noise are shown in Figure 1. As seen in Figure 1, there was no apparent difference among the spectral forms of the types of noise we used. This suggests that the difference of spectral form was unlikely to have affected the results of our psychophysiological experiment. For practical reasons, the energy-mean value of the sound pressure level of the above noises was adjusted to approximately 50 dB. In addition, the following conditions were tested.

(c) No external noise

Intellectual task

In this study, the odd-ball paradigm and the probe-digit task were adopted as cognitive tasks (details described below).

(A) Odd-ball paradigm

The odd-ball paradigm is typically used to examine selective attention and information processing capacity (S.Sutton et al. 1965). 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 was 2,000 Hz tone burst (‘rare’) with an occurrence probability of 20 %. The frequent-rare sequence was randomly presented with an inter-stimulus interval of 2 s. Stimuli were presented binaurally at 50 or 60 dB, and 120 ms duration (including 10 ms rise-fall time and 100 ms plateau) through in-ear earphones. The subject’s task was only to count the ‘rare’ stimuli for approximately 5 min. This task was repeated twice for each noise condition.

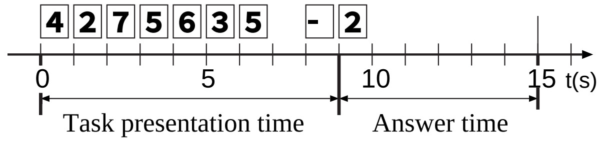


Figure 2: Time chart of probe-digit task

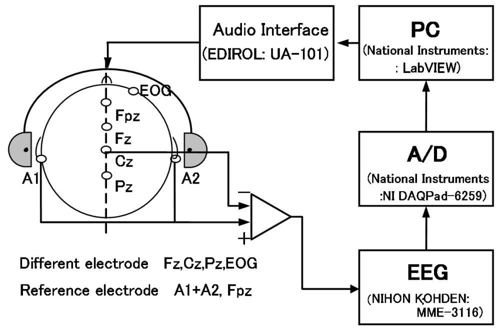


Figure 3: Measurement system of auditory evoked ERPs

(B) Probe-digit task

The probe-digit task was adopted as a typical short-term memory task. The general procedure was as follows. Based on results of previous studies, the span of immediate memory we used was approximately seven items in length (Miller 1956). A sequence of seven single digits was presented with the aid of a standard table of random numbers, under the constraint that no digit appeared more than twice in a row. Figure 2 shows the time chart of the probe-digit task. Seven single digits were presented per second. After the presentation of the seven single digits, the last digit, which was one that had occurred only once before, was presented. The subject’s task was to push the number of the digit that had followed the probe-digit in the sequence on the answer input device as quickly as possible. Digits from 2 to 9 were used from the ”CD for the evaluation of fitting condition with hearing aids (TY-89)”, and were read by a male speaker. Maximum band levels measured with a sound level meter were adopted as the band levels of speech peaks. The overall sound pressure level of the speech peaks was approximately 62 dB. It was confirmed that all of the digits could be heard under each of the masking conditions. To aid the subject in detecting the end of a sequence, a pure tone of 1,000 Hz was presented between the seventh digit and the probe-digit. Because the probe-digit was unique in the sequence, there was only one possible correct answer for any trial. The time allowed for selecting answers was longer than 5 s. The subjects were instructed not to push any number if they did not know the correct answer. This 15 s sequence was repeated 60 times (15 minutes) for each noise condition. The repetitive probe-digit task was carried out only once a day to avoid fatigue. The first day of the psychophysiological experiment was treated as practice and, unknown to the subject, was not scored.

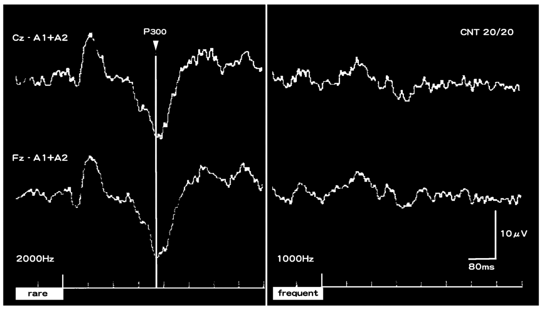


Figure 4: ERPs waveform to ‘rare’ and ‘frequent’ stimuli

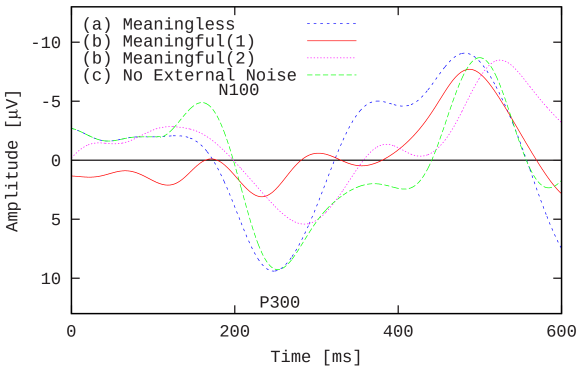
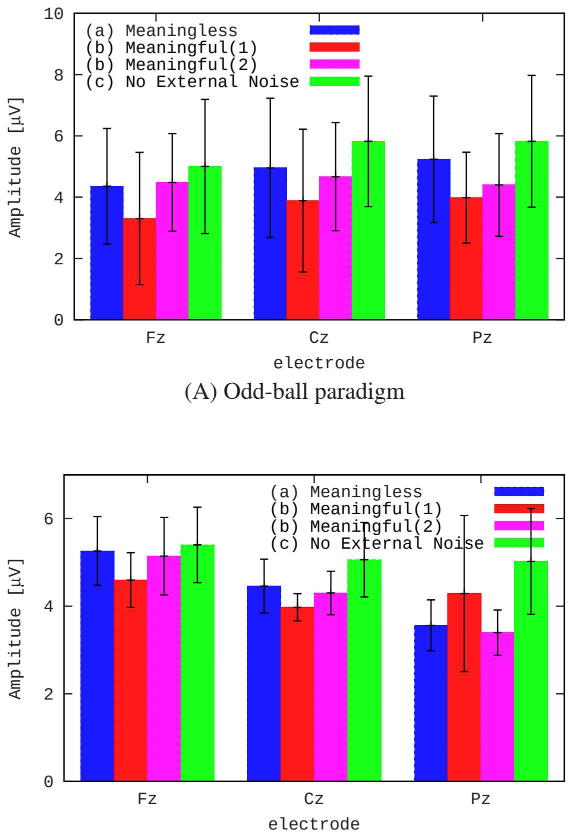


Figure 5: ERPs waveform to ‘rare’ stimulus in odd-ball paradigms under each noise condition



(A) Odd-ball paradigm

(B) Digit-probe task

Figure 6: P300 amplitude of ERPs

Measurements

Participants were seated in a sound-attenuated electrically shielded room. Figure 3 shows our measurement set-up for recording auditory evoked ERPs. The auditory signal was generated by a PC and presented over headphones through an audio interface. Electroencephalogram (EEG) was recorded from three locations (Fz, Cz and Pz) on the midsagittal line of scalp based on 10-20 system with Ag/Ag Cl electrodes of which impedance was held below 5 kΩ. Electrodes were referenced to linked earlobes, and the ground electrode was placed on the midforehead electrode (Fpz). The electro-oculogram (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 0.5 to 30 Hz, and recorded with 16-bit quantization level at sampling rate of 4 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. As an example of waveform of ERPs after stimulus-triggered averaging to ‘rare’ and ‘frequent’ stimuli is shown in Figure 4.

Various psychological evaluation scales are available for quantifying the psychological evaluation of noise. We used a classification system with seven levels of annoyance experienced: (F1: Not at all annoying, F2: Not annoying, F3: Not too annoying, F4: Slightly annoying, F5: Annoying, F6: Very annoying, F7: Extremely annoying) (Furihata and Yanagisawa 1989). Subjects were instructed to evaluate the noise during completion of intellectual tasks. We examined the percentage of correct answers and reaction time as measures of task performance. The number of correct answers was checked and the percentage of correct answers calculated. The time it took to push the button to identify the stimulus was defined as the reaction time. This calculation did not include incorrect answers or responses without an answer.

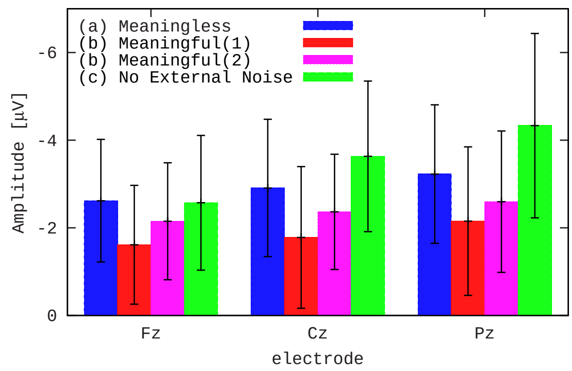
EFFECT OF MEANINGFULNESS OF NOISE

Event-related potentials

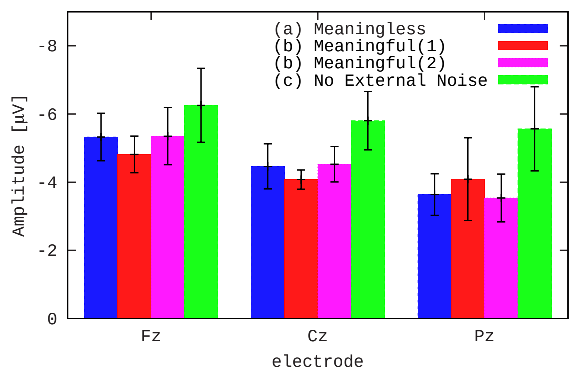
It is well established that ERPs elicited by internal or external stimuli, can be measured using EEG (Cacioppo et al. 2000). The P300 component of the ERP is a positive peak occurring around 300 ms after presentation of stimuli, in response to detected perceptual signals. The P300 is thought to reflect the resolution of uncertainty or the perceptual decision that an expected signal has occurred. The peak amplitude and latency of this component is related to selective attention and working memory.

The N100 component of the ERP is a negative-going evoked potential that peaks around 100 ms after the onset of a stimulus. The N100 is thought to represent the activation of neural assemblies involved in the analysis of incoming sensory information. We calculated N100 and P300 amplitude by subtracting the baseline voltage derived from the average off-line the EEG for 200 ms before staring the presentation of target tone bursts, from the peak voltage in the 70 - 125 ms and 250 - 500 ms latency windows.

Averages and standard deviations of the P300 amplitude in the ERP were calculated for each noise condition. Figure 6 shows



(A) Odd-ball paradigms



(B) Digit-probe task

Figure 7: N100 amplitude of ERPs

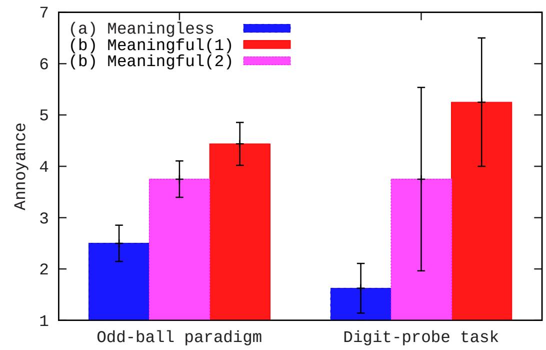


Figure 8: Annoyance

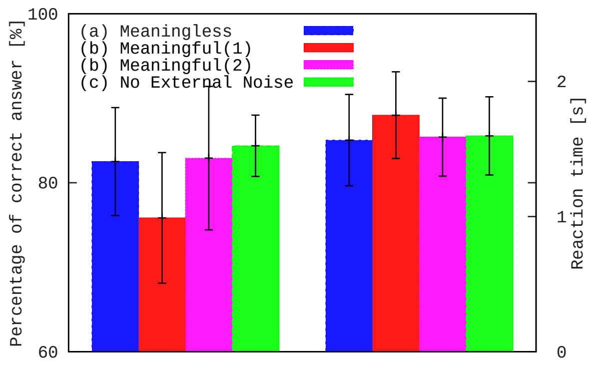


Figure 9: Task performance

the P300 amplitude results in the odd-ball and digit-probe tasks. To investigate whether the differences in P300 amplitude were significant, we conducted a two factor repeated-measure analysis of variance (ANOVA) (noise condition [meaningless, meaningful (1), meaningful (2), no external noise] and electrode position [Fz, Cz, Pz]). A *post-hoc* multiple comparison (Fisher's LSD test) was also used. These analyses revealed significant main effects of noise condition and electrode position ($p < .05$), but no significant interaction between these factors. Moreover, in the odd-ball paradigm, we found statistically reliable differences in the P300 amplitude between the meaningful noise (1) and other noises at each electrode position. Averages and standard deviations of N100 amplitude for each noise condition in the odd-ball and digit-probe tasks, are shown in Figure 7. Similarly to our P300 amplitude results, an ANOVA of the N100 amplitude revealed significant main effects of noise condition and electrode position ($p < .05$). In addition, a *post-hoc* multiple comparison revealed significant differences between meaningful noise (1) and other noise types in the odd-ball paradigm. These results indicate that attention to the 'rare' stimulus was influenced by the degree of meaningfulness of the noise during completion of an cognitive task.

Subjective experience of annoyance

Averages and standard deviations of the subjective experience of annoyance in response to the noise were calculated for each noise condition. Figure 8 shows the results for annoyance in the odd-ball and digit-probe tasks. The difference in subjective experience of annoyance between meaningless and meaningful noise conditions was examined with a repeated-measures ANOVA (noise condition [meaningless, meaningful (1) and meaningful (2)]). The ANOVA revealed a significant main effect of noise condition ($p < .01$) in both cognitive tasks. In addition, a *post-hoc* multiple comparison revealed significant differences in the subjective experience of annoyance between meaningless and meaningful noise conditions. These results demonstrated that the subjective experience of annoyance in response to noise increased by up to approximately 1 - 3 (on the category scale) due to the meaningfulness of the noise.

Task performance

Averages and standard deviations of the percentage of correct answers and reaction times were calculated for each noise condition in the digit-probe task. The percentage of correct answers and reaction times appear in Figure 9. The results revealed a slight decline in the percentage of correct responses and a small delay in response time due to the meaningfulness of the noise.

CONCLUSION

This study focused on the effects of the meaningfulness of noise. We examined the effects of meaningful noise and meaningless noise on psychophysiological activity while carrying out cognitive tasks. Specifically, the P300 and N100 components of the ERPs elicited by the auditory odd-ball and the digit-probe tasks, were measured using EEG. The electrophysiological results revealed significant differences between the peak amplitudes of P300 and N100 component between meaningless and meaningful noise. In addition, we tested whether relationships between the meaningfulness of a noise and the resulting subjective experience of annoyance and task performance correlated with a quantitative index of the percentage of correct answers and reaction time change, during the completion of repetitive auditory probe-digit tasks. The results revealed that whether the noise is meaningless or meaningful had a strong influence on selective attention to auditory stimuli in cognitive tasks. This effect was related to the subjective experience of annoyance and task performance. 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 noise that is likely to be present.

ACKNOWLEDGMENTS

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