ICIC Express Letters
Part B: Applications
Volume **9**, Number **3**, March **2018**

ICIC International ©2018 ISSN 2185-2766
pp. 195–201

EFFECTS OF ACTIVE CONTROL OF NOISE WITH MUSIC ON SUBJECTIVE AUDITORY IMPRESSION AND BRAIN ACTIVITY

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Received September 2017; accepted December 2017

Abstract. *The influence of active noise control (ANC) on auditory impression of required sound other than noise was investigated by psychological measurement and magnetoencephalography (MEG). We created 15 types of stimulus sounds consisting of music and noise (five levels of ANC were applied for three pieces of music). The paired-comparison test showed that the score of the subjective preference for the sample music #1, which has the lowest spectral centroid among stimuli, showed a significant decrease as the ANC level increased. MEG measurements were also performed for the sample music #1 and temporal stability of spontaneous responses was estimated for θ, α, β, and low-γ ranges. The temporal stability of the low-γ bands showed negative correlation with the preference score of the stimuli. The results indicate that ANC decreases sound quality in some cases, and consequently greater information processing resources are required for recognition of unpreferred stimuli.*
Keywords: Active noise control, Magnetoencephalography, Auditory impression

1. **Introduction.** Active noise control (ANC) is a noise-reduction technique that works by the addition of one or several secondary sources to the original sound source [1,2]. ANC is especially suitable for reducing low-frequency noise where traditional passive noise control techniques based on sound-absorbent materials and acoustic screens are ineffective. Therefore, ANC techniques are widely used for cars, headphones, and so on. Recently, ANC systems have been equipped in a car cabin [3].

It is thought that ANC reduces loudness of noise, but also changes auditory impressions. However, few studies have focused on the quantitative effects of ANC on auditory impressions. Ito et al. reported that annoyances of car engine noises were reduced by applying ANC [4]. On the other hand, Gonzalez et al. reported that auditory impressions of car engine noises were deteriorated by applying ANC in case the noise had smoother spectrums, whereas auditory impressions were improved in most cases [5]. Their reports indicate the possibility that ANC decreases the preference of sound in some cases.

Usually, assessment of sound quality is carried out using subjective psychological tests such as the paired-comparison method and semantic differential method. However, such psychoacoustic tests usually compel participants to repeat judgments over and over, and often take a long time. Furthermore, it is sometimes hard to obtain an entirely reliable evaluation. It is comparatively easy to improve the sound quality if we can also use an objective measure corresponding to the auditory impression. It is thought that usage of neurophysiological data is one of the most reliable methods. In recent years, changes in auditory impression due to music and songs are attempting to be clarified by brain activity measurement [6-8]. We previously examined to reveal the relationships between the brain cortical neural activities and subjective preference or annoyance of sounds [9,10]. In these studies, magnetoencephalographic (MEG) components in the 8-13 Hz range, i.e., alpha activities, were recorded and analyzed using an auto-correlation function (ACF). It was found that the effective duration of the ACF, τ_e, which is related to repetitive features within the signal itself, was lengthened for the preferred stimuli [8] and shortened for the annoyed stimuli [9].

In this study, we investigated the influence of ANC with positive and meaningful sound on auditory impression by psychological measurement and magnetoencephalography (MEG). First, the scale values of preference for stimulus sounds were obtained by paired-comparison tests in each participant. Next, MEG measurements and the ACF analyses were conducted using the sample music #1, which showed a significant decrease of preference by applying the ANC. The relationships between subjective preference and the factors extracted from the ACF in the brain's magnetic responses were investigated.

This experiment had prior approval from the Ethical Committee of the National Institute of Advanced Industrial Science and Technology (AIST), Japan, and a written informed consent was obtained from each participant after an explanation of the nature and purpose of the experiment.

2. Methods.

2.1. Stimulus. We chose 10 pieces of classical music from the free available database [11]. Each piece of music was cut into about 3 s to suit music, and 18-sample music nominees were created. Then, three sample sounds showing the largest, median, and smallest values of the A-weighted spectral centroid were selected (spectral centroid: music #1: 620 Hz, music #2: 1099 Hz, music #3: 2061 Hz).

We used white noise as a primary signal $x(n)$. Both sample music $s(n)$ and white noise $x(n)$ were adjusted to 60 dB(A). Figure 1 shows a block diagram of the ANC used in this experiment. $H(z)$ and $P(z)$ are the 1st plants. Causality changes according to the input

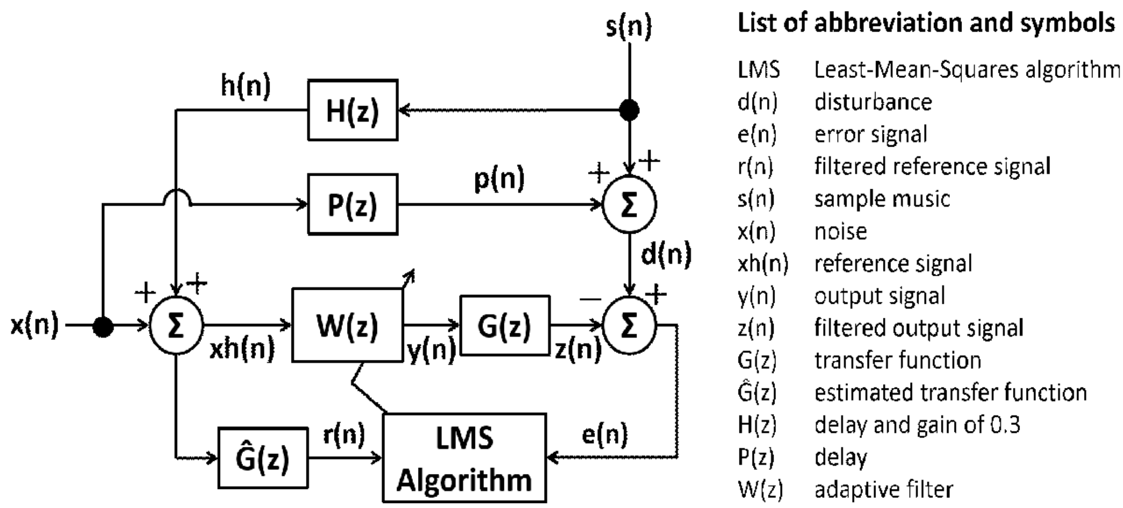

FIGURE 1. Block diagram of ANC evaluated

sample delay and the reduction effect changes as well. In this study, three different 12-sample delays were adopted. $G(z)$ is the 2nd plant and $\hat{G}(z)$ is the 2nd plant model. The 2nd plant is low-pass filter (LPF) having a seventh-order finite impulse response (FIR) and a cutoff frequency of 500 Hz.

The five stimulus conditions are A (without applying ANC), B (ANC applied, and 1-sample delay in the 2nd plant), C (ANC applied, and 3-sample delay in the 2nd plant), D (ANC applied, and 5-sample delay in the 2nd plant), and E (ANC applied, and 12-sample delay in the 2nd plant). 15 types of stimulus sounds (three sample music, each with five ANC patterns of A, B, C, D, and E) were created. ANC was performed for more than 20 s until convergence. Then, we mixed sample music into it. All stimuli used in the experiment had duration of 7 s.

2.2. **Subjective evaluation using a paired-comparison.** Nineteen normal-hearing participants (4 females and 15 males; mean age 24.95 years, range 19-49, all right-handed) took part in the experiments. They were seated in a soundproof room with a comfortable thermal environment. Stimulus sounds were delivered to both ears using an insertion-type earphone (ER-2, Etymotic Research Co. Ltd.). Scheffe's paired-comparison tests were performed for all combinations of the pairs of stimulus, i.e., 105 pairs ($N(N-1)/2$, $N = 15$) of stimuli with a different order of each pair per session, and random presentation of the pairs. Each pair of stimuli was presented four times to determine the scale value of preference. Participants took three experiments each 5-min rest between experiments. Pairs of sounds were presented, and participants were asked to judge their preference on a 7-point scale. The scale values of the preference were calculated according to Scheffe's theory [12].

2.3. **Magnetoencephalography.** MEG measurements were carried out when participants heard the sample music #1. Ten normal-hearing participants (1 female and 9 males; mean age 25.27 years, range 19-49, all right-handed), who underwent the subjective evaluation test as the previous experiment, took part in the MEG measurements. They were seated in a magnetically-shielded room with a comfortable thermal environment.

During measurements, participants were requested to carry out Thurstone's paired-comparison tests [13] for all combinations of stimuli, i.e., 10 pairs ($N(N-1)/2$, $N = 5$) of stimuli with a different order of each pair per session, and random presentation of the pairs. They were asked to judge which they preferred. The auditory stimuli were presented using the same earpieces as in the paired-comparison test.

Recordings of magnetic fields were carried out using a 122-channel whole-head neuromagnetometer (Neuromag-122$^{\text{TM}}$, Neuromag Ltd., Helsinki, Finland). The effective durations of ACF of the spontaneous oscillations, the temporal stability of brain oscillation, τ_e, were calculated from MEG data. We extracted 1.5-2.5 seconds of sample music listening time from the brain magnetic field data. We extracted the alpha wave through a filter of between 8-13 Hz that were located around the occipital area selected for the ACF analysis. Similarly, we extracted the theta wave through a filter between 4-7 Hz, the beta wave through a filter between 13-30 Hz, and the low-gamma wave through a filter between 20-50 Hz. Similar oscillatory activity observed over the auditory cortex is called τ rhythm. Each response corresponding to one stimulus was analyzed by the ACF for each participant. The relationships between the degree of preference and averaged τ_e values at 26 sites, measured at two tangential derivatives, were investigated.

3. **Results.**

3.1. **Subjective evaluation using a paired-comparison.** Figures 2, 3 and 4 show the scale values of the preference for each stimulus. Stimulus A was a control stimulus without applying ANC, and stimuli B through E utilize ANC.

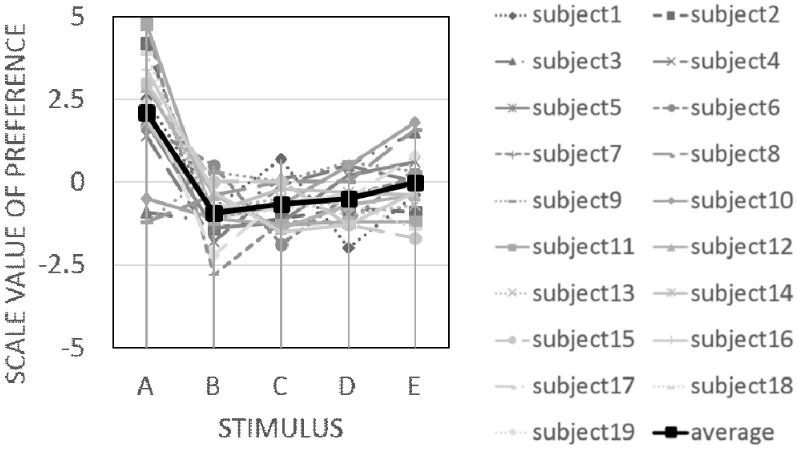

FIGURE 2. The scale values of the preference for each stimulus of sample music #1. The five stimulus conditions are A (without applying ANC), B (ANC applied, and 1-sample delay in the 2nd plant), C (ANC applied, and 3-sample delay in the 2nd plant), D (ANC applied, and 5-sample delay in the 2nd plant), and E (ANC applied, and 12-sample delay in the 2nd plant). The reduction effect increases as the input sample delay increases.

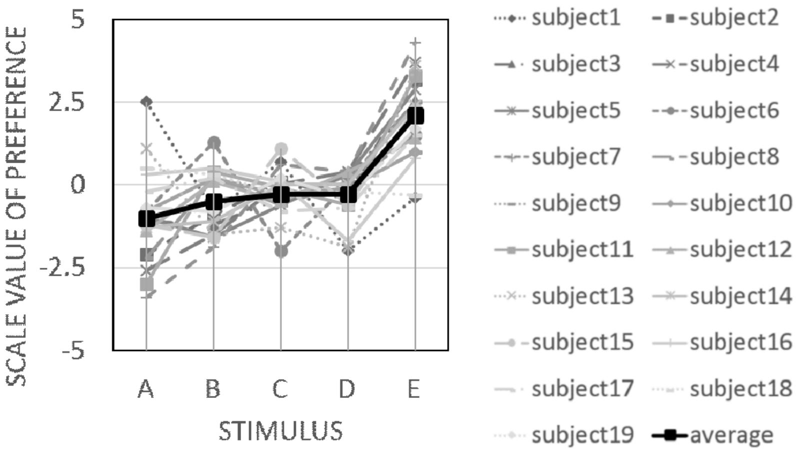

FIGURE 3. The scale values of the preference for each stimulus of sample music #2. The five stimulus conditions are A (without applying ANC), B (ANC applied, and 1-sample delay in the 2nd plant), C (ANC applied, and 3-sample delay in the 2nd plant), D (ANC applied, and 5-sample delay in the 2nd plant), and E (ANC applied, and 12-sample delay in the 2nd plant). The reduction effect increases as the input sample delay increases.

Analysis of variance (ANOVA) was performed to analyze the tendency of stimulus and preference. In sample music #1, the scale value of preference showed the significant decline for ANC-applied stimuli ($F(4, 90) = 22.38$, $p < 0.05$). However, in sample music #2, the scale value of preference showed the significant increase for ANC-applied stimuli ($F(4, 90) = 27.81$, $p < 0.05$). In the same manner, in sample music #3, the scale value of preference showed the significant increase for ANC-applied stimuli ($F(4, 90) = 6.55$, $p < 0.05$).

When ANC is applied to a sound in which noise and music are mixed, the noise is reduced and the ratio of noise to sample music (SNR: Signal-to-Noise Ratio) becomes large.

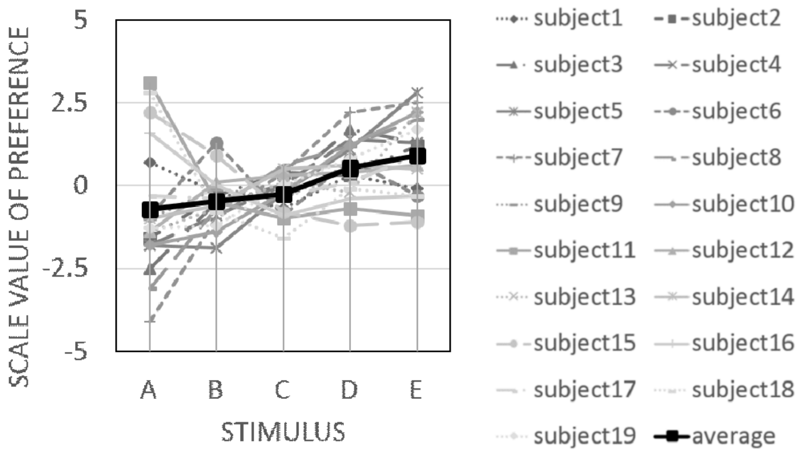

Figure 4. The scale values of the preference for each stimulus of sample music #3. The five stimulus conditions are A (without applying ANC), B (ANC applied, and 1-sample delay in the 2nd plant), C (ANC applied, and 3-sample delay in the 2nd plant), D (ANC applied, and 5-sample delay in the 2nd plant), and E (ANC applied, and 12-sample delay in the 2nd plant). The reduction effect increases as the input sample delay increases.

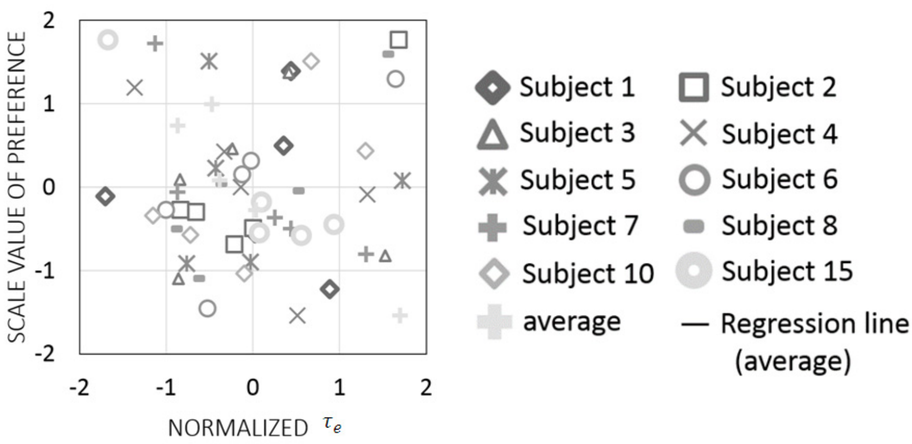

Figure 5. Relationship between preference and τ_e in the alpha band

Analysis of linear regression was performed to analyze the relationship between SNR and preference. In sample music #1, the correlation coefficient between SNR and preference was significant ($r = 0.94$, $p < 0.05$). In sample music #2 and #3, the correlation coefficient was not significant ($r = 0.50$, $p = 0.40$ and $r = 0.39$, $p = 0.52$).

3.2. **Magnetoencephalography.** Figures 5 and 6 show relationships between the scale values of preference obtained in the paired-comparison tests and τ_e estimated in the occipital region. No significant correlation was observed in the alpha bands as shown in Figure 5. However, the effective duration τ_e in the low-gamma bands became shorter while listening to preferred stimulus, and there was a significant negative correlation as shown in Figure 6 ($r = -0.60$, $p < 0.05$).

4. **Discussion.** For the sample music #1, the subjective preferences declined under ANC in 16 of the 19 participants. The fluctuation of the preference value by the stimulus was significant by linear regression analysis and ANOVA. In this experiment, it is thought that the reduction of noise has a positive influence on auditory impressions, while the

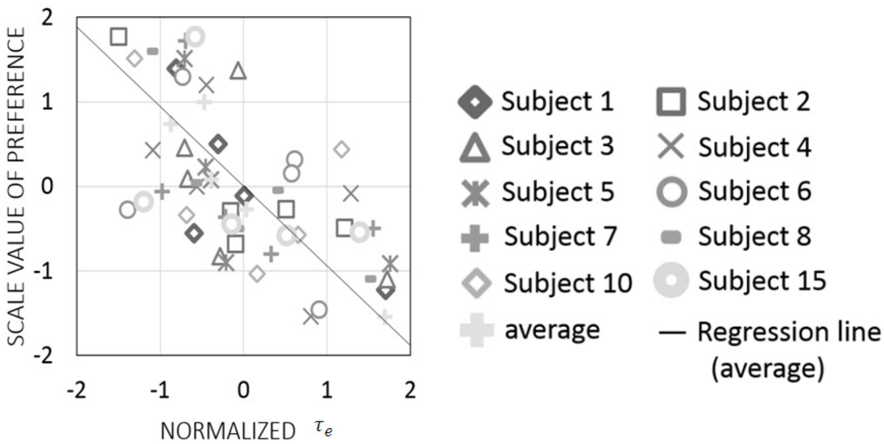

FIGURE 6. Relationship between preference and τ_e in the gamma band

influence of the sound quality of the sample music has a negative influence on the auditory impression. Therefore, it is thought that the negative effect of the influence of the music sound quality was greater than the positive effect due to the reduction of noise. Conversely, there was no decline under ANC in 3 out of the 19 participants, in which instance, there was a tendency that it is preferable as the noise is smaller in sample music #2 and #3. It is assumed that the positive effect of the reduction of noise is greater than the negative effect on the influence of the sound quality of music.

Further, temporal stability (effective duration of ACF) of spontaneous MEG responses was estimated. In the previous research [9], the effective duration of ACF (τ_e) in the alpha bands (8-13 Hz) became longer when listening to the preferred stimulus. In this study, however, similar results were not observed in the alpha band. It is thought that the temporal stability of the alpha band is highly correlated with the 'primitive' preference induced by intrinsically comfortable sound. Therefore, the alpha band may not be suitable for the evaluation of the 'staticy' sound used in this experiment.

On the other hand, the gamma band is thought to reflect the higher order cognitive processing. In this study, significant negative correlation exists between the effective duration of ACF (τ_e) in the low-gamma bands (20-50 Hz) and the preference for the sample music #1. This result suggests that information processing resources for recognition of the music might be increased as the music becomes unpreferred. More detailed study is needed to discuss a relationship between the low-gamma brain activities and the preference of sounds.

5. **Conclusion.** The influence of ANC with meaningful sound on auditory impression was investigated by psychological measurements and MEG. The score of the subjective preference for the sample music #1, which has the lowest spectral centroid among stimuli, showed a significant decrease as the ANC level increased. Further, the temporal stability of the low-gamma bands showed negative correlation with the preference score of the stimuli. The results suggested that ANC decreases sound quality in some cases, and greater information processing resources are required for recognition of unpreferred stimuli. In this study, we do not consider acoustic features of sounds. It is conceivable that the acoustic parameters of stimulus may influence subjective evaluation. In further research, we would like to examine the relationship between subjective evaluation and acoustic features of music in detail.

Acknowledgment. This work was partly supported by a Grant-in-Aid for Scientific Research (B) (Grant No. 15H02771) from the Japan Society for the Promotion of Science.

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