The effects of the aircraft noise and multiple echoes on speech intelligibility of outdoor public address system

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ABSTRACT

This study investigates how multiple echoes reflected from adjacent buildings influence the speech intelligibility of outdoor public address systems when aircraft noise is added. To accomplish this, the sound of an aircraft flying over industrial areas was recorded from the vicinity of an airport in Tokyo and then added to speech sounds at a signal-to-noise ratio (SNR) of -5 dB. Then, the speech signals, with or without artificial multiple echoes, were presented to 18 young adults at sound pressure levels (SPLs) of 60, 70, and 80 dB. The results of the listening test showed that aircraft noise and multiple echoes separately decreased speech intelligibility, but that speech with the multiple echoes present had significantly lower word identification scores than speech without multiple echoes. The results also showed that speech intelligibility increased when the SPLs was increased from 60 to 70 dB, but no further increase was observed when the SPLs rose from 70 to 80 dB, with or without multiple echoes. Taken together, the results indicate that both aircraft noise and multiple echoes decrease the speech intelligibility of outdoor public address systems, and to ensure sufficient information is transmitted when multiple echoes and aircraft noise are present, SPLs should not be lower than 70 dB.

Keywords: Aircraft noise, Multiple echoes, Sound pressure level, Outdoor public address system
I-INCE Classification of Subjects Numbers: 13.1.5, 23.9, 52.9, 63.3

1. INTRODUCTION

Outdoor public address (PA) systems are one of the most popular methods of prompt information propagation and are used in a wide variety of situations such as when searching for missing persons, disseminating evacuation and disaster preparation information, or broadcasting air pollution warnings. However, when used in urban areas, some residents point out that speech announcements broadcast from the outdoor PA systems are difficult to hear, and various local governments have responded by adjusting loudspeaker directions and outdoor PA system volumes. Therefore, it can be stated that speech pronouncements of current outdoor PA systems are not sufficiently intelligible.

There are a number of factors responsible for decreasing the speech intelligibility of outdoor PA systems. First, it can be presumed that multiple echoes, consisting of long-delay reflected sounds (i.e., longer than 50 ms from the sound source) would have a significant influence on listener comprehension [1]. Second, loud aircraft noise in the vicinity will obviously decrease the speech intelligibility of outdoor PA systems. Such aircraft noise is generally loud in residential areas close to airports, but previous studies [1, 2] have not directly addressed correlations between speech intelligibility and aircraft noise.

While the problems associated with aircraft noise are gradually improving in general, the problems related to aircraft noise have not been settled [2]. Also, it would be difficult to restrict aircraft noise more thoroughly because, in general, air traffic control laws govern aviation routes and aviation safety has priority over aircraft noise abatement considerations.

The signal-to-noise ratio (SNR) and sound-pressure-level (SPL) of speech announcements and aircraft noise must also be addressed when the speech intelligibility of outdoor PA systems is considered. A SPL of 73 dB or more is generally sufficiently intelligible within a 100 m radius of an outdoor PA system loudspeaker in Japan, which corresponded to 64 dB of the SPL within a 300 m radius where speech announcements are to be audible in Japan [3]. However, according to aircraft noise surveys reported by the

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Tokyo Metropolitan Government Environment White Paper 2013 [4], the Weighted Equivalent Continuous Perceived Noise Level (WECPNL) in the vicinity of the airport ranged from 46 to 47 dB which corresponded to 73 dB of the average power of aircraft noise, and therefore SNR will be lower than 0 dB in that area.

The goal of this study is to contribute to the speech intelligibility of outdoor PA systems in residential areas affected by aircraft noise. To accomplish this, the authors investigated how multiple echoes influenced the speech intelligibility of outdoor PA systems when an aircraft flew over a residential area, focusing on the multiple echoes that decrease listener comprehension. More specifically, 18 young adults were subjected to listening tests during which spoken sentences were presented with aircraft noise (SNR of -5 dB), and with or without artificial multiple echoes. The stimuli presentation levels were 60, 70, and 80 dB. After which, the word correct rate of the listening test was calculated for each condition.

2. LISTENING TEST

2.1 Participants

As mentioned above, 18 young native speakers of Japanese, who were self-reported to have normal hearing, participated in this study.

2.2 Original speech sentences

The original speech sentences used in the listening test were 120 Japanese target words embedded in a Japanese carrier sentence. The target words were four *"morae"* (Japanese phoneme unit) and their word familiarity was 2.5 to 4.0 on a seven-point scale (7: most familiar to 1: least familiar) [5]. The carrier sentence used was similar to one heard normally in the spoken outdoor PA systems announcements of numerous local governments. (Such as, "This is an announcement from the local government office".)

The narrator of the original speech sentences was a 23-year-old male native Japanese speaker who was recorded in a soundproof room. The original speech sentences were recorded by a microphone (SHURE, KSM141) connected to an audio interface (TASCAM, US-144MKII) and a computer (Hush Technologies, GmbHMini-ITX). The carrier sentence and target words were recorded separately. Next, the amplitude of the carrier sentence and the 120 target words were normalized by MATLAB software. Finally, each target word was embedded into the carrier sentence using Praat software.

2.3 Speech stimuli

Table 1 shows the experimental condition: three SPL conditions (60, 70, and 80 dB) and two multiple echo conditions (with or without the multiple echoes). The SPLs of this study were selected based on a previous report stating that outdoor PA system SPLs tended to exceed 64 dB within a 300 m radius of the loudspeakers [3].

In this study, the artificial multiple echoes were created at delay times of 650 and 1450 ms using MATLAB numerical analysis software. The delay times were selected based on a simulated impulse response of an outdoor PA system [6].

Figure 1 shows the aircraft noise measurement location at the *Jonanjima* seaside park in Tokyo's Ota Ward. The aircraft noise was recorded using a microphone (SHURE, KSM141) connected to a portable SD recorder (Marantz, PMD661). After analyzing all the recorded aircraft noise, a period when the background noise level (e.g., ship noises, people speaking, bird calls) was low was selected for use. The yellow and green line in Fig. 1 designates the flight path of the aircraft at the time the recording was made. This information was from the flightradar24 website [7]. The red circle indicates the measurement/recording spot.

In order to create the needed stimuli, the original speech sentences were first convolved with the multiple echoes. Next, the aircraft noise was added to the speech sentences at a SNR of -5 dB. The total number of stimuli was 720. Specifically, three SPLs × two multiple echoes (with or without) × 120 original speech sentences). In order to counterbalance the combination of the conditions and target words, 20 original speech sentences were assigned per condition for each participant. Therefore, 120 stimuli (three SPLs × two multiple echoes × 20 original speech sentences) were assigned to each participant.

2.4 Procedure

The listening test was conducted in a soundproof room. The stimuli were presented using headphones (STAX, SR-303) via a driver unit (STAX, SRM-323A) and an audio interface (TASCAMUS, 144MKII) connected to a computer (Hush Technologies, GmbHMini-ITX). The listening test interface was produced

Table 1 – Listening test conditions

Listening condition	Sound pressure level (dB)	Multiple echoes
1	60	With
2	60	Without
3	70	With
4	70	Without
5	80	With
6	80	Without

Table 2 – Aircraft noise measurement conditions

Date and time	July 13, 2013 16:00-17:00
Weather	Cloudy
Temperature	32.5 degrees Celsius
Humidity	52%
Recording place	*Jonanjima* Seaside Park, Tokyo
File format	Format: WAVE Sampling frequency: 44.1kHz Audio channel: Monaural

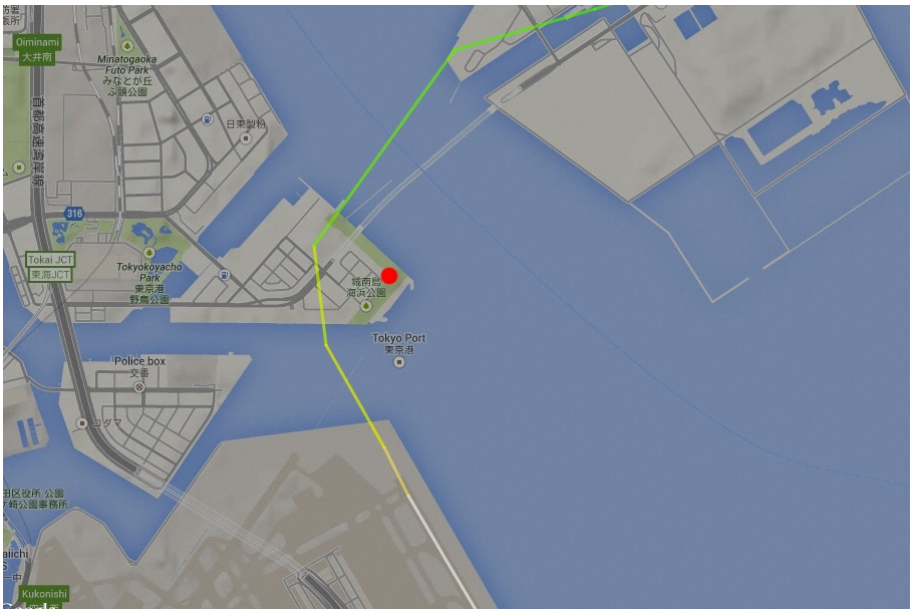

Fig. 1 – Aircraft noise measurement/recording location
(The yellow and green line indicates the aircraft flight path [7]. The red circle shows the measurement/recording location.)

using Praat software. Each participant received two practice sessions before the actual listening test was conducted. After the practice sessions, the 120 stimuli described in Section 2.3 were presented to the participants. The stimuli presentation order was randomized for each condition, and the target words and conditions were counterbalanced for each participant. During the test, each participant wrote down the target words they heard on answer sheets in Kana orthography.

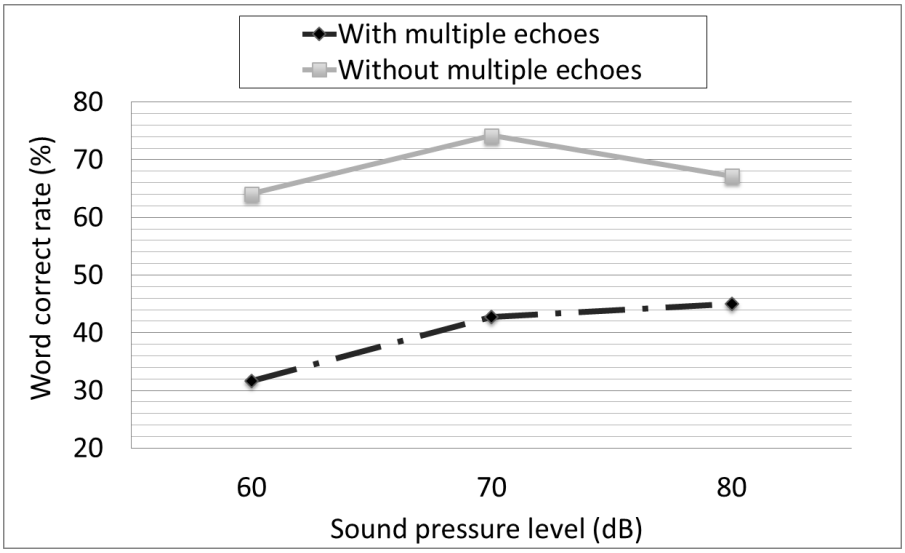

Fig. 2 – Results of listening test

(The dashed black line shows the result word correct rate results when multiple echoes were present. The gray line shows the word correct rate without multiple echoes.)

3. Experimental results and discussion

Figure 2 shows the mean word correct rate for each condition. The repeated measures analysis of variance (ANOVA) was carried out under two multiple echo conditions (with or without) and three SPL conditions (60, 70, and 80 dB) using IBM SPSS statistics software. The main effect of the multiple echoes was statistically significant (p<0.05), showing that the word correct rate with the multiple echoes was lower than that without the multiple echoes. Also, the main effect of the SPL is statistically significant (p<0.05), indicating that the word correct rate decreased as the SPL decreased. The interactions between the multiple echoes and the SPL were not statistically significant. In other words, the word correct rate decreased in tandem with the SPL, with or without the multiple echoes. A Sidak multiple comparison test was conducted on the SPLs. The word correct rate at SPL of 60 dB was significantly lower than that at SPL of 70 dB (p<0.05).

A separate ANOVA was carried out for the conditions with or without multiple echoes. The main effect of SPL was only statistically significant when the multiple echoes were present (p<0.05). Changes to the SPL did not affect the word correct rate when there were no multiple echoes. A Sidak multiple comparison test on the SPLs showed a statistically significant difference between the SPL of 60 and 70 dB, and between 60 and 80 dB (p<0.05). This indicates that, when the multiple echoes were present, the word correct rate at the SPL of 60 were lower than that at 70 dB, and at 80 dB.

As in the previous study [1], the word correct rate with the multiple echoes was 28.7% lower on average than that without the multiple echoes (32.4, 31.4 and 22.2% at SPLs of 60, 70 and 80 dB respectively), although the delay time of multiple echoes in that study [1] was different than those used in this study. Therefore, it is determined that multiple echoes are one factor to decrease speech intelligibility of outdoor PA systems.

This study showed that the aircraft noise decreased the word correct rate an additional 10% when compared with the condition without aircraft noise. In the SPLs of 60 and 70 dB conditions, the word correct rate with the multiple echoes was about 30 % lower than that without the multiple echoes. Also, the previous study [1] reported that the sentence intelligibility with multiple echoes of 500 ms was about 20% lower than that without the multiple echoes when SPLs of outdoor PA system were 56 and 67 dB. Taken together, the word correct rate with the aircraft noise condition were about 10% lower than that without the aircraft noise condition.

When the SNR of the speech sentences and the aircraft noise was -5 dB, the maximum word correct rate with the multiple echoes was 45%. In actual outdoor PA systems, it can be estimated that the speech intelligibility may be less than 45% when the SNR is lower than -5 dB because the previous study [8]

pointed out that the speech intelligibility decreased as the SNR decreased. According to the previous studies [3, 4] the mean peak level of the aircraft noise was 73 dB and the SPL of 64 dB and more was generally intelligible enough within a 300 m radius from a loudspeaker of the outdoor PA system. Thus, in the actual outdoor PA systems, the speech intelligibility will be quite low (e.g., lower than 45%) when the SNR will be lower than -5 dB.

With the multiple echoes, the word correct rate was significantly increased when the SPL was increased up to 70 from 60 dB. In actual outdoor PA systems, increasing SPL of the outdoor PA system up to 70 dB may contribute to increase SNR of speech announcements of outdoor PA system and the aircraft noise. Therefore, when limiting the SPL alone, it deemed desirable to set SPL to 70 dB for improving speech intelligibility of outdoor PA systems.

4. CONCLUSIONS

This study evaluated the effects of aircraft noise and multiple echoes on the speech intelligibility of outdoor PA systems. From the results, it was found that when the aircraft noise was added, the word correct rates when multiple echoes were present were significantly lower than when they were not. Also, compared with the previous study [1], the word correct rate with the aircraft noise condition were about 10% lower than that without the aircraft noise condition. The results also showed that the word correct rates at an SPL of 70 dB were significantly higher than those at an SPL of 60 dB, but that the word correct rate did not increase significantly between SPLs of 70 and 80 dB, regardless of whether or not multiple echoes were present. Based on these results, we determined that increasing the SPLs of speech announcements can increase the speech intelligibility of outdoor PA systems, but may end up causing further noise problems. Therefore, other solutions to increase speech intelligibility of outdoor PA systems need to be considered.

Our future studies will examine how aircraft noise directions and speech announcement enhancements affect the speech intelligibility of outdoor PA systems, while also continuing to explore means of controlling outdoor PA system SPLs. Specifically, since a previous study pointed out that the speech intelligibly of outdoor PA systems was affected by the direction of the speech announcement in addition to multiple echoes [1], it is believed that outdoor PA system speech intelligibly will be affected by the direction of aircraft noise relative to that of the speech announcements. Furthermore, since another study pointed out that the dominant frequency components of the aircraft noise changed depending on the types of aircraft [8], it may be possible to increase the speech intelligibility of outdoor PA systems by enhancing speech signals in frequency regions that are relatively unaffected by aircraft noise.

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