Comparison of noise characteristics in airplanes and high-speed trains

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This study investigated the characteristics of noise in trains and airplanes to determine its effect on passengers. The noise was recorded using a dummy head or binaural microphones. The data were analyzed using an autocorrelation function (ACF) and an interaural cross-correlation function (IACF). From the ACF analysis, the following were analyzed: (1) the energy represented at zero delay, $\Phi(0)$, which corresponds to the equivalent continuous A-weighted sound pressure levels, L_{Aeq}, (2) the time delay of the first maximum peak, τ_1, (3) its amplitude, ϕ_1, which corresponds to the pitch and pitch strength, and (4) width of the first decay, $W_{\Phi(0)}$, which corresponds to the spectral centroid. From the IACF analysis, the interaural cross-correlation coefficient (IACC), which corresponds to subjective diffuseness, and the width of the peak, W_{IACC}, which corresponds to apparent source width, was analyzed. The median values of L_{Aeq} were approximately 73−77 dB in airplanes and 64−72 dB in high-speed trains. The values of τ_1 in high-speed trains were centered approximately 2, 3, and 4 ms The values of τ_1 in airplanes were centered approximately 4 and 6 ms. The values of IACC in high-speed trains was very high.

Key words: Autocorrelation function (ACF), Interaural cross-correlation function (IACF), Sound quality

1. INTRODUCTION

In Japan, considerable attention has been given to the environmental noise generated by public transport systems and their effects on nearby residents. A great deal of research has also been done on the sound level as it affects car passengers. However, there is little research on the sound quality in public transport systems and its effects on passengers. Given the dominance of public transport in Japan, the quality of sound in public transport systems and their effects on passengers needs further study.

Many people use public transport systems, such as airplanes and trains for extended periods. Noise in airplanes and trains can stress and fatigue passengers and interfere with their ability to understand the public address system. Therefore, the acoustic comfort of public transport systems should be maximized. In previous studies, only the sound pressure levels in airplanes and trains have been measured [1]. However, measurements of the sound pressure level alone are not enough to characterize the acoustic comfort because other factors related to sound quality such as pitch, pitch strength, and diffuseness also affect the level of stress and fatigue passengers experience [2, 3].

Although a great deal of research has been done on the noise emitted by the airplanes and trains and its effect on nearby residents, there are relatively few studies on the noise inside airplanes or trains. To improve the acoustic comfort and the ability of passengers to understand public address systems, it is necessary to clarify the characteristics of noises from a quantitative and qualitative point of view. In this study, L_{Aeq} and selected parameters related to sound quality were used to characterize the noises inside both airplanes and trains [3, 4]

2. METHODS

Noise in airplanes was measured on four domestic Japanese flights, four high-speed journeys on the Shinkansen train in Japan, and one return journey on the TransRapid train in China In addition, noise on five normal speed train journeys was measured for comparison. The noise was recorded using a dummy head (Neumann: KU100) or binaural microphones (Type 4101; B&K) positioned approximately 1.6 m above the

Fig. 1. Experimental apparatus – Dummy head microphone setup.

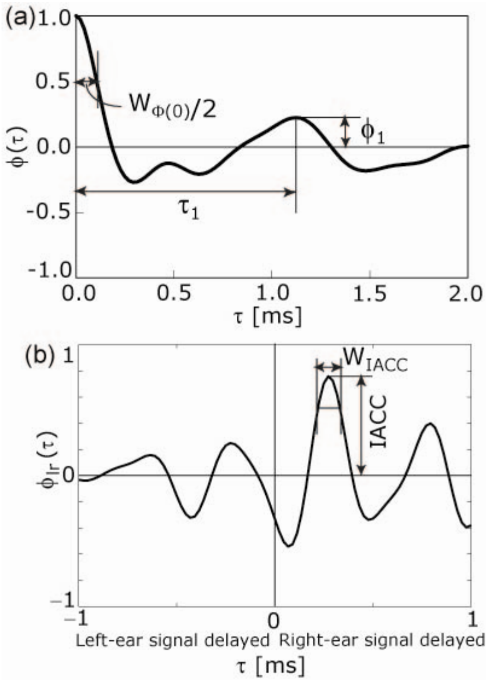

Fig. 2. Definitions of parameters extracted from (a) ACF and (b) IACF.

floor level as shown in Fig. 1. The data from the microphones were analogue-to-digital converted with a 32-bit sound card and a sampling rate of 48 kHz.

The recorded data were analyzed by autocorrelation function (ACF) and interaural cross-correlation function (IACF) [2]. The normalized running correlation function is defined by:

$$\phi_{lr}(\tau;t,T) = \frac{\Phi_{lr}(\tau;t,T)}{\sqrt{\Phi_{ll}(0;t,T)\Phi_{rr}(0;t,T)}}, \quad (1)$$

where $\Phi_{ll}(0; t, T)$ is the ACF of the left-ear signal, $\Phi_{rr}(0; t, T)$ is the ACF of the right-ear signal and $\Phi_{lr}(\tau; t, T)$ is the IACF. The IACF of a signal from left or right ear, $p_{l,r}(s)$, is defined by:

$$\Phi_{lr}(\tau;t,T) = \frac{1}{2T}\int_{t-T}^{t+T} p_l{}'(s)p_r{}'(s)ds, \quad (2)$$

where 2T is the integral interval, τ is the time delay, and $p_{l,r}'(s)$ is obtained after passing through the A-weighted network, which approximately corresponds to the sensitivity of the ear, $s(s)$, so that $p_{l,r}'(s) = p_{l,r}(s)*s(s)$.

From the ACF analysis, (1) the energy represented at zero delay, $\Phi(0)$, which corresponds to the equivalent continuous A-weighted sound pressure levels, L_{Aeq}, (2) the time delay of the first maximum peak, τ_1, which corresponds to pitch, (3) its amplitude, ϕ_1, which corresponds to pitch strength, and (4) the width of the first decay, $W_{\Phi(0)}$, which corresponds to the spectral centroid, were analyzed. From the IACF analysis, the interaural cross-correlation coefficient (IACC), (which is defined as the maximum of the IACF and related to subjective diffuseness), and the width of the peak, W_{IACC}, (which is

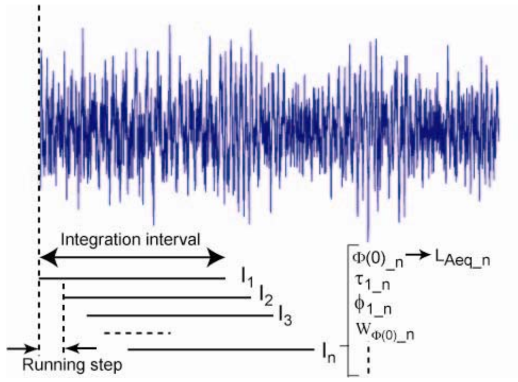

Fig. 3. Concept of short-time moving ACF analysis along the noise.

defined as the width of the maximum and related to apparent source width), were analyzed. The ACF and IACF parameters are shown in Fig. 2.

The sound quality metrics, such as Loudness and Sharpness, which reflect the transfer characteristics of the outer and middle ear and both frequency and temporal masking [4], were also analyzed. Loudness is a single index calculated from the loudness chart based on the measured one-third octave-band levels of a noise. Sharpness is a measure of the high frequency content of a sound. The greater the proportion of high frequencies, the 'sharper' the perception of the sound is.

The ACF, IACF, and sound quality metrics were calculated along the duration of the noise as shown in Fig. 3. In all calculations, the integration interval was 0.5 s, and the running step was 0.1 s. Figure 4 shows examples of parameters L_{Aeq} and τ_1 as a function of time. These temporal variations are very complicated, because there are so many kinds of noises, such as rolling, curve squeal, impact noises. Then, we do not focus on each noise afterward.

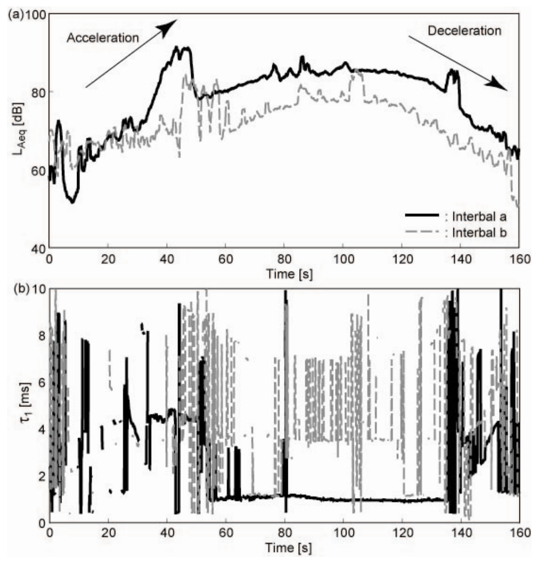

Fig. 4. Examples of factors (a) L_{Aeq} and (b) τ_1 as a function of time in an interval of normal speed train.

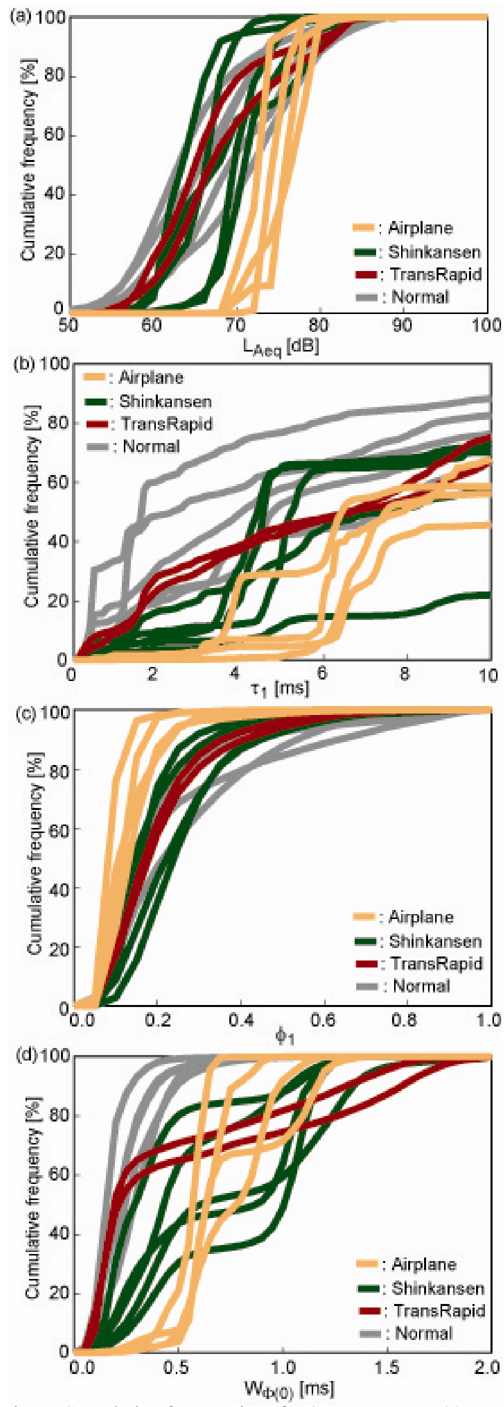

Fig. 5. Cumulative frequencies of ACF parameters, (a) L_{Aeq}, (b) τ_1, (c) ϕ_1, and (d) $W_{\Phi(0)}$.

3. RESULTS

Figure 5(a)-(d) shows the cumulative frequencies of L_{Aeq}, τ_1, ϕ_1, and $W_{\Phi(0)}$ for each airplane or train journey. There was a tendency for the L_{Aeq} in airplanes to be greater than that in high-speed trains although there was a little difference between the values for airplanes and high-speed train. The values of τ_1 in airplanes were centered at approximately 4 and 6 ms, which correspond to a pitch of 250 and 167 Hz. The τ_1 values for

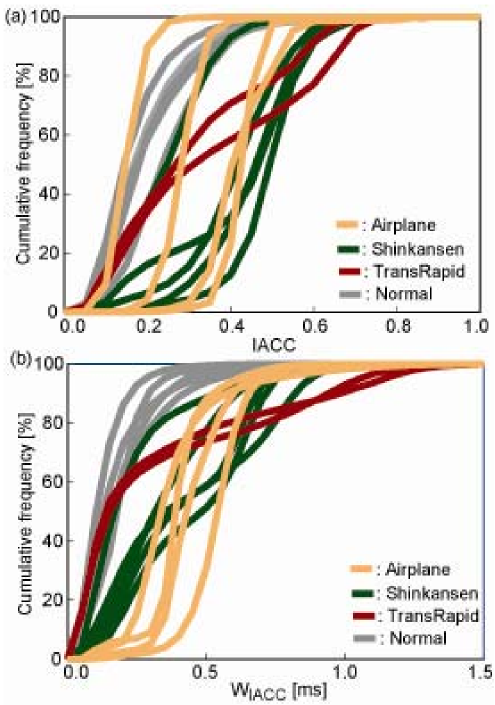

Fig. 6. Cumulative frequencies of IACF parameters, (a) IACC and (b) W_{IACC}.

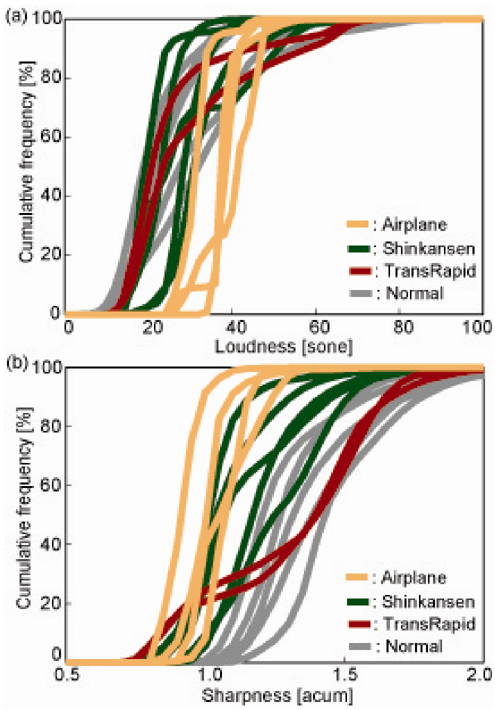

Fig. 7. Cumulative frequencies of sound quality metrics, (a) Loudness and (b) Sharpness.

high-speed trains were centered at approximately 2, 3, and 4 ms, which correspond to a pitch of 500, 333, and 250 Hz. The values of ϕ_1 in high-speed trains were larger than that in airplanes. The values of $W_{\Phi(0)}$ in airplanes were centered approximately 0.6, 0.8, and 1.0 ms. The values of $W_{\Phi(0)}$ in high speed trains were centered approximately 0.2, 0.4, and 1.0 ms.

Figure 6(a) and (b) shows the cumulative frequencies of IACC and W_{IACC} for each airplane and train journey. The difference of IACC values between routes of airplanes was quite large. The median values of IACC in high-speed trains were more than 0.4 except for one route, which is quite large compared with airplanes and normal speed trains. The variation of W_{IACC} values in high-speed trains was larger than that in airplanes and normal speed trains.

Figure 7(a) and (b) shows the cumulative frequencies of Loudness and Sharpness for each airplane and train journey. Loudness in airplanes was greater than that in high-speed trains. The Loudness and L_{Aeq} results are very similar. In general, Sharpness was greater in high-speed trains than in airplanes.

4. DISCUSSION

The median value of L_{Aeq} in airplanes was 73–77 dB and greater than that in high-speed trains, suggesting the need for more noise control. High-speed trains travel at more than 200 kilometers per hour and generate more noise compared with normal speed trains that travel at 70–80 kilometers per hour [5]. However, L_{Aeq} and Loudness in high-speed trains was almost the same as that in normal speed trains. This reconfirms the high level of noise control in high-speed trains.

The τ_1 values for airplanes are much longer than for trains. This means the pitch of noises in airplanes is much lower and totally different from that in trains. In high-speed trains, typical τ_1 values were 2, 3, and 4 ms, which corresponds to a pitch of 500, 333 and 250 Hz. These are mainly generated by rolling noise [6]. The mode value of τ_1 in high speed trains is smaller than that in airplanes, indicating that the pitch in high-speed trains is higher. This might reduce the perceived loudness in airplanes. In addition, the variation of τ_1 in high-speed trains is smaller than that in normal speed trains. Noises with a greater τ_1 variation are perceived as being more annoying [2]. Therefore, passengers in normal speed trains might perceive the noise as more annoying than the noise in high-speed trains.

The ϕ_1 value is closely related to the strength of the pitch [7]. The ϕ_1 values in high-speed trains were greater than those in airplanes, suggesting that the perceive pitch of the noises is stronger in high-speed trains.

The median value of IACC in high-speed trains is much greater than that in normal speed trains, suggesting that the perceived image of the sound source in high-speed trains is much smaller than that in normal speed trains. This might be caused by aerodynamic noise. The variation of IACC in high-speed trains is greater than that in airplanes. Increasing the variations of IACC increases the annoyance caused by a noise [8]. Therefore, the noise in high-speed trains might be more annoying than that in airplanes from a spatial point of view. The difference in IACC values between different airplanes is quite large. The position of the seats, volume, or internal shape of the aircraft might affect the IACC.

In this study, the noises in public transportation systems was characterized using ACF and IACF. ACF and IACF parameters, such as τ_1, ϕ_1, and IACC are closely related to the sound quality of a noise [9, 10]. Therefore, factors extracted from the ACF and IACF could be useful criteria for evaluating the sound quality of environmental noise.

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