Enhancement of acoustic environment with regard to speech privacy and annoyance in passenger cars of high-speed trains

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ABSTRACT

This study aims to determine the optimal acoustic environment in passenger cars of high-speed trains considering speech privacy and noise annoyance. Listening tests were conducted to examine the relationship between speech privacy and noise annoyance. In the first session, speech intelligibility was evaluated using Korean sentences with respect to background noise and speech sources. In the second session, participants were asked to read articles in a passenger car with conversations and interior noise and then to assess the speech privacy and noise annoyance. The auditory tests were performed for varying background noise levels and signal-to-noise (S/N) ratios. Using the results, an optimal level of interior noise, taking speech privacy and annoyance into consideration, was suggested to improve the acoustic comfort in passenger cars of high speed trains.

INTRODUCTION

The Korea Train eXpress (KTX) line began operation in 2004, and a high-speed domestic line, the KTX-Sancheon, began operation in 2010. High-speed train systems are one of the most important modes of public transport in Korea. As the number of passengers of KTX has grown, the need for acoustic comfort in passenger cars has increased. Accordingly, many studies of the sound qualities of interior noises in trains have been conducted focusing on noise annoyance (Hardy, 2000; Patsouras et al., 2002; Parizet et al., 2002). However, in addition to noise caused by the train, passengers are another source of annoying sounds in passenger cars (Jeon et al. 2014; Kuwano et al., 2004; Maffei et al. 2012; Patsouras et al., 2000). It is necessary to investigate the interior noise of high-speed trains from the perspectives of both noise annoyance and speech privacy to enhance acoustic comfort in high-speed trains. Thus, this study aims to determine the optimal range of background noise levels considering noise annoyance and speech privacy. To achieve this goal, auditory experiments were conducted for varying background noise levels and S/N ratios of speech sound to interior noise.

METHOD

Experimental design

Laboratory experiments comprised two sessions. Experiment 1 was designed to investigate the effects of the background noise and S/N ratio on speech intelligibility. For background noise, interior noises in a high-speed train were recorded at the seat in the middle of the passenger car using a binaural microphone (B&K, Denmark, Type 4101) and a field recorder (Zoom, Japan, H4N) when the train was running on ballast tracks in open fields at speeds of 100, 200, and 300 km/h. For laboratory

experiments, 3-s audio samples of the interior noises were excerpted from the recording. Phonetically balanced Korean sentences recorded in an anechoic chamber were used as the speech material. There were three interior background noise levels: 60, 63, and 66 dBA at 100, 200, and 300 km/h, respectively. The S/N ratio was varied from -15 to 6 dBA in steps of 3 dBA. In total, 24 cases of combined noises were created. During the auditory experiments, five test sentences were presented to each individual in random order for each of the 24 test situations. Thus, each participant listened to a total of 120 test sentences in random order. Speech intelligibility scores were assigned according to the fraction of words that were correctly understood.

In Experiment 2, speech privacy and noise annoyance were evaluated for the combination of interior noises and conversation sounds using a 5-point scale to determine the optimal background noise and S/N ratio for acoustic comfort in high-speed trains. As in Experiment 1, 24 cases were created, with variation among the three levels of interior noises and eight levels of S/N ratio.

Procedure

Thirty university students with normal hearing ability, comprising 21 males and 9 females, participated in Experiments 1 and 2. The age distribution of the subjects ranged from 20 to 29 years (mean: 24.0, standard deviation: 2.0). The experiment was performed in a testing booth (4 m × 3 m) with approximately 25 dBA of background noise. After listening to the speech source, the listener repeated the recognized words. The degree of correspondence between the proposed sentence and the recognized sentence was rated for each syllable in the sentence. Ratings of word intelligibility were derived from the results of the listening test. Individuals were instructed to imagine that they were sitting on a seat in a high-speed train compartment. The sounds were presented to the subjects through a headphone (Sennheiser HD 650) in an auditory test booth.

RESULTS

Experiment 1: Speech intelligibility test

Figure 1(a) shows the mean speech intelligibility scores with respect to the S/N ratio. It was found that the speech intelligibility score dramatically increased when the S/N ratio R increased from -9 dBA to -6 dBA. The subjects recognized approximately 50% of sentences at S/N ratio of -6 dBA. Speech intelligibility scores were higher than 70% when the S/N ratio increased over -3 dBA. Figure 2(b) illustrates the mean speech intelligibility scores with respect to the background noise levels. There were no significant differences in the speech intelligibility scores among background noise levels. This indicates that the SNR significantly affected the speech intelligibility scores, while the effects of interior noise levels in the high-speed train were not significant.

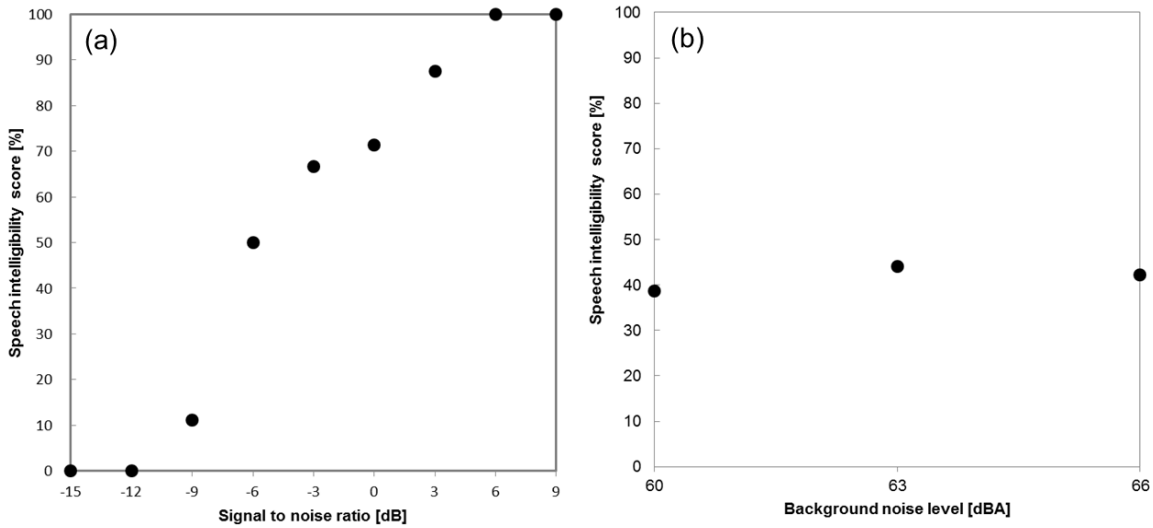

Figure 1. Mean speech intelligibility scores as functions of (a) S/N ratio and (b) background noise level

Experiment 2: Speech privacy and noise annoyance test

Figure 2(a) shows the percentages of subjects who gave a rating of ‘4’ or ‘5’ on the 5-point rating scale with regard to speech privacy as a function of the S/N ratio. It was shown that the percentage of subjects reporting high speech privacy dramatically decreased when the S/N ratio increased from -6 dBA to -3 dBA. More than 70% of subjects reported high speech privacy when the S/N ratio was below -6 dBA, and less than 20% of subjects reported high speech privacy when the S/N ratio was below -3 dBA.

Figure 2(b) presents the percentages of respondents who gave a rating of ‘4’ or ‘5’ on the 5-point rating scale with regard to noise annoyance as a function of the S/N ratio. In contrast with the percentage for high speech privacy, the percentage of highly annoyed people increased as the S/N ratio increased. Specifically, the percentages of highly annoyed people were similar (below 30%) between -15 dBA and -6 dBA, whereas the percentage of highly annoyed respondents was found to increase significantly when the S/N ratio was over -3 dBA.

Figures 3(a) and 3(b) show the percentage of subjects reporting high speech privacy and the percentage of subjects highly annoyed, respectively, in terms of background noise levels. As in Experiment 1, significant differences in the percentage for speech privacy according to the background noise levels were not observed, as shown in Figure 3(a). This confirms that the background noise level affects speech intelligibility and speech privacy. The background noise level also influences the noise annoyance, as shown in Figure 3(b). The percentages of highly annoyed subjects significantly increased more than 60% with background noise level greater than 63 dBA. It is shown that interior noise levels between 60 dBA and 63 dBA may be appropriate considering noise annoyance in a passenger car of a high-speed train.

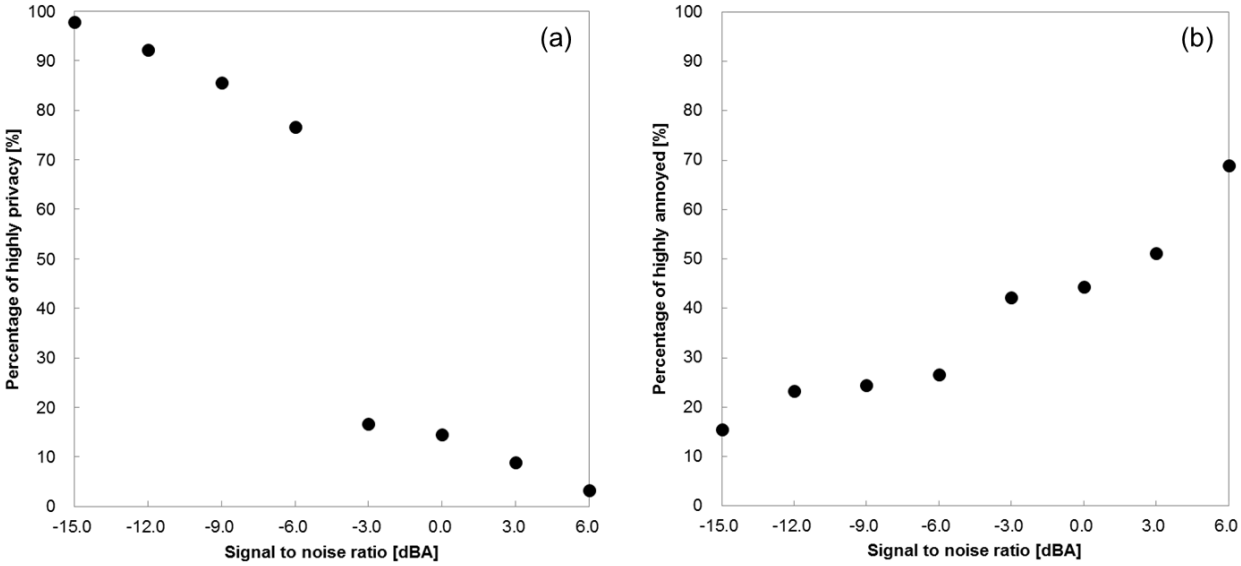

Figure 2. Percentage of subjects (a) reporting high speech privacy and (b) highly annoyed as functions of S/N ratio

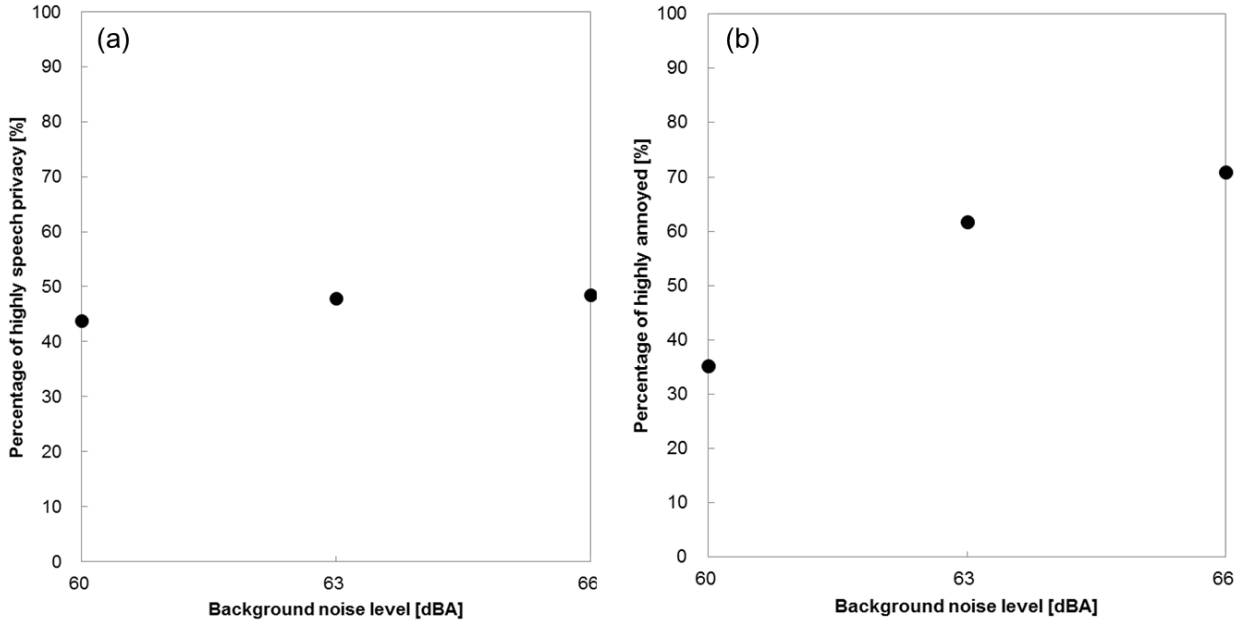

Figure 3. Percentage of (a) highly privacy and highly annoyed as a function of background noise level

CONCLUSIONS

In this study, the effects of the interior noise levels in a passenger car of a high-speed train and the S/N ratio of speech to background noise on speech intelligibility, speech privacy, and noise annoyance were investigated using auditory experiments. It was found that speech intelligibility significantly increased as S/N ratios increased from -9 dBA to -6 dBA. Regarding speech privacy, the percentage of respondents

who reported that speech privacy was good significantly decreased when the SNR increased over -3 dBA. Although the effects of background noise levels on speech intelligibility and speech privacy were not determined, the noise annoyance was found to increase as the background noise level increased. In particular, the percentage of highly annoyed respondents considerably increased by approximately 20–30% when the interior noise was greater than 63 dBA. According to the results for speech intelligibility and speech privacy, the optimal S/N ratio may be -6 dBA. Speech effort is approximately 60 dBA. Thus, it can be suggested that the optimal range of background noise levels in a passenger car taking both speech privacy and noise annoyance into account is from 60 to 63 dBA.

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