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Psychological evaluation of sound environment in a compartment of a high-speed train

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Abstract

Sound environment in a compartment of high-speed trains (Shinkansen) was examined in relation to speech communication and annoyance. Three experiments were conducted. In Experiment 1, the annoyance caused by the compartment noise was judged. In Experiment 2, both the compartment noise and the conversation were presented together and the annoyance of the combined sounds was judged. In Experiment 3, both sounds were presented and only the disturbance of conversation was judged. The results showed that: The annoyance of compartment noise showed good correlation with L_{Aeq}. The annoyance of the combination of the compartment noise (N) and the conversation (C) increased as C/N decreased. There was, however, a tendency that annoyance increased as C/N increased in some conditions. This suggests that there exists an optimum level of compartment noise at 50–60 dBA taking the level of conversation into consideration. The disturbance of the conversation increased as C/N increased. However, when the level of conversation became high, it was judged as being disturbing regardless of the level of compartment noise.

1. Introduction

Many studies have been conducted concerning the sound quality of the compartment noise of transportation systems [1–8]. They have focused on the effect of tonal components [1,2], spectrum

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shapes [3], effective metrics to measure the quality of compartment noise [3], the evaluation and/or improvement of specific sounds in a compartment [4–7]. Kuwano [9] pointed out that the conversation of other passengers might possibly be a noise source in a compartment. Patsouras et al. [10] investigated the intelligibility of speech in relation to the disturbance of privacy in a compartment of high-speed trains. They also examined the effect of shielding between passengers.

A preliminary questionnaire survey was conducted about the annoyance of compartment noise with 182 respondents who had experience to take a high-speed train (Shinkansen). More than half of the respondents answered that the compartment noise in Shinkansen was quiet. Only about 4% of the respondents answered that it was annoying. The results of another preliminary questionnaire survey conducted with 41 respondents found that many respondents felt unpleasant if other passengers were talking loudly in Shinkansen. Also, it was found that many respondents had an experience to make their voice softer when they talked with their friends in Shinkansen so that they might not disturb other passengers.

These results suggest that the compartment noise of Shinkansen itself seems to have little problems, and that the conversation may be one of the main noise sources in the compartment of Shinkansen. Passengers do not want to be disturbed by the conversation of other passengers and do not want to disturb other passengers by their own conversation, either. In this study, sound environment of a compartment of Shinkansen was examined in relation to speech communication and annoyance. Three experiments were conducted.

2. Experiment 1

In Experiment 1, the annoyance of the compartment noise of Shinkansen was judged alone. The annoyance means the nuisance aspect of the sound. This is an experiment conducted in a laboratory and the annoyance judged may be different from the daily life experience. Therefore, the annoyance judged should be called "reported annoyance" as indicated by Rice [11] though the term only annoyance" is used in this paper.

2.1. Stimuli

The stimuli used in Experiment 1 are shown in Table 1. The sounds were recorded in the three types of Shinkansen, i.e. series 100, 300 and 700. They were recorded in various seats in various running conditions. Frequency characteristics of these sounds are shown in Fig. 1. The L_{Aeq} values were set at 55, 60, 65, 70 and 75 dB taking the actual levels into consideration. In total, 15 sounds were used. The duration was 10 s.

2.2. Procedure

Fifteen sounds were presented in random order. A subject was seated alone in a sound proof room and instructed to judge the annoyance using seven categories from very quiet to very annoying. Before experiment, the subject had training with three sounds, which were not used in the experiment. The subject was informed that the sounds were the compartment noise of Shinkansen.

Table 1
Stimuli used in Experiment 1

No.	Type of Shinkansen	L_{Aeq}	No.	Type of Shinkansen	L_{Aeq}
1	Series 100	55	9	Series 700	75
2	Series 100	60	10	Series 700	70
3	Series 100	65	11	Series 700	75
4	Series 700	60	12	Series 700	75
5	Series 700	65	13	Series 700	60
6	Series 700	70	14	Series 700	55
7	Series 700	65	15	Series 300	55
8	Series 700	70			

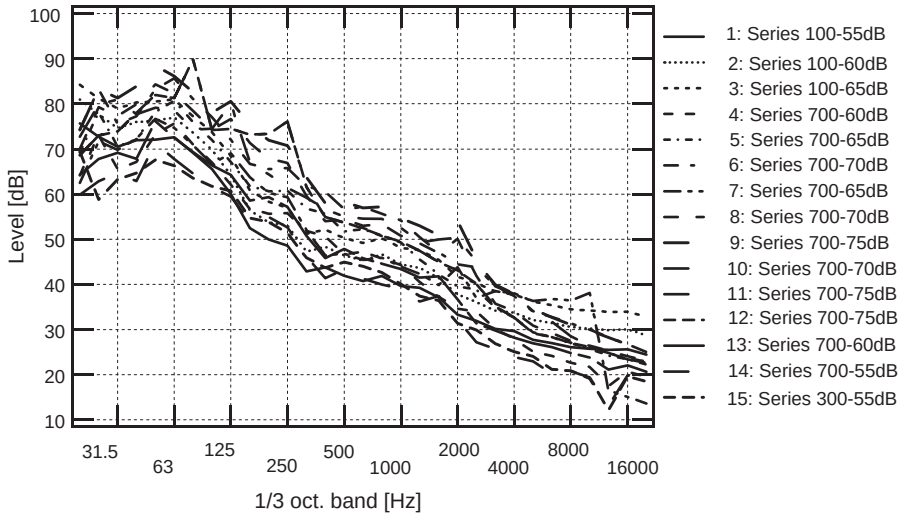

Fig. 1. Frequency characteristics of the compartment noises of Shinkansen used in Experiment 1. Thin straight lines, thick straight lines and dashed lines indicate 1/3 octave band level of series 700, 300 and 100 respectively. The overall sound levels ranged from 55 to 75 dB.

2.3. Equipment

The sounds were reproduced with a hard disk recorder (AKAI DR8) and presented to subjects through an amplifier (Victor A-X5) and loudspeakers (Diatone DS-800ZX) in a soundproof room.

2.4. Subjects

Seven females and five males aged between 21 and 25 with normal hearing ability participated in Experiment 1.

2.5. Results

The judgments of 12 subjects were averaged and correlated with L_{Aeq} of Shinkansen compartment noise. Although category scale is an ordinal scale, it can usually be admitted as an interval scale in the case of quantitative judgment of sounds [12]. Therefore, simple average was used in this experiment. The relation between annoyance and L_{Aeq} of Shinkansen compartment noise was high as shown in Fig. 2. There was little difference in the frequency characteristics among the sounds used in Experiment 1.

3. Experiment 2

In Experiment 2, the annoyance of the combination of conversation and compartment noise of Shinkansen was judged.

3.1. Stimuli

The stimulus conditions are shown in Table 2. The compartment noise of Shinkansen (N) was recorded in a compartment of Nozomi, series 700, when the train was running smoothly. The casual conversation (C) between two people, one female and one male, was recorded from internet radio program which was free from copyright. The frequency characteristics of the compartment noise and the conversation are shown in Fig. 3. The L_{Aeq} value of the compartment noise was varied from 45 to 75 dB and that of conversation was varied from 25 to 65 dB. Both sounds were combined as shown in Table 2. When the level of compartment noise was higher than that of conversation by 40 dB, the conversation was not audible and such combination was not used. Therefore, in total 57 combined sounds were used in Experiment 2.

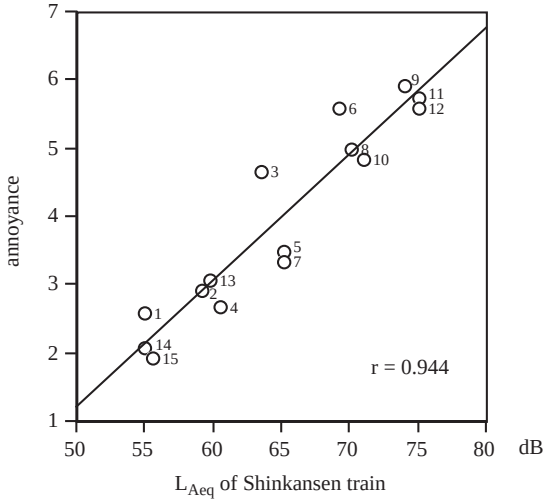

Fig. 2. Result of Experiment 1. Good correlation was found between L_{Aeq} and annoyance of compartment noise.

Table 2
Stimulus combinations used in Experiment 2

Compartment noise (dB)	Conversation (dB)								
	65	60	55	50	45	40	35	30	25
75	*	*	*	*	*	*	-	-	-
70	*	*	*	*	*	*	*	-	-
65	*	*	*	*	*	*	*	*	-
60	*	*	*	*	*	*	*	*	*
55	*	*	*	*	*	*	*	*	*
50	*	*	*	*	*	*	*	*	*
45	*	*	*	*	*	*	*	*	*

57 combinations indicated by * were used.

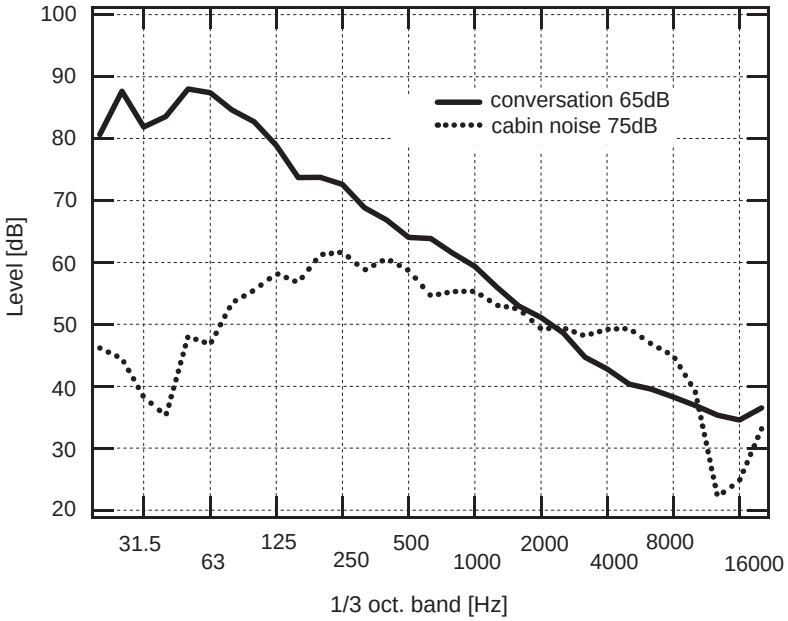

Fig. 3. Frequency characteristics of compartment noise (indicated by straight line) and conversation (indicated by dotted line) used in Experiment 2.

3.2. Procedure

The 57 combinations of compartment noise and conversation were presented to subjects in random order. Subjects were asked to judge the annoyance of both sounds as a whole, using seven categories from very quiet to very annoying.

3.3. Equipment

Both sounds were reproduced with a hard disk recorder (AKAI DR8) and presented to subjects in a soundproof room through amplifiers and loudspeakers. Different amplifiers (Victor A-X5 and Victor A-X77) and different loudspeakers (Diatone DS-800ZX and Quad Pro-63) were used for presenting the compartment noise and the conversation, respectively.

3.4. Subjects

Eight females and 12 males aged between 20 and 43 with normal hearing ability participated in Experiment 2.

3.5. Results

The judgments of 20 subjects were averaged. The relation between L_{Aeq} of the combined sounds and the annoyance is shown in Fig. 4. Generally, the annoyance of combined sounds increased as the values of L_{Aeq} increased and a fairly high correlation was present ($r = 0.843$). There were some deviations where the annoyance varied even if the values of L_{Aeq} were equal. The higher the level of conversation, the more annoying the combined sounds was judged suggesting that the effect of conversation was important.

Fig. 5 shows the annoyance judgment plotted against C/N. It can be seen that the annoyance increases as C/N becomes lower, i.e. the level of compartment noise becomes higher. It can also be seen that as the higher the level of conversation became, the more annoying the combined sounds was judged. However, the relation is not a linear function when the level of conversation was

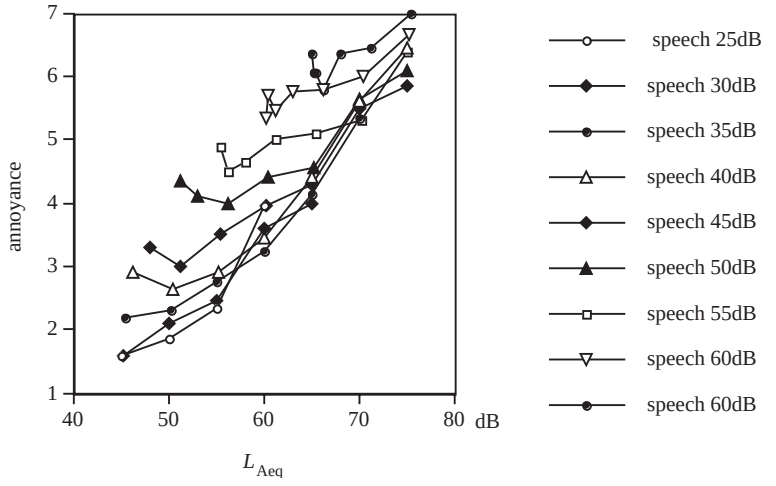

Fig. 4. Relation between L_{Aeq} and annoyance of the combination of compartment noise and conversation. Open circles, filled diamonds, filled circles, open upward triangles, open diamonds, filled upward triangles, open squares, open downward triangles and filled downward triangles indicate the conditions of speech levels of 25, 30, 35, 40, 45, 50, 55, 60 and 65 dB respectively.

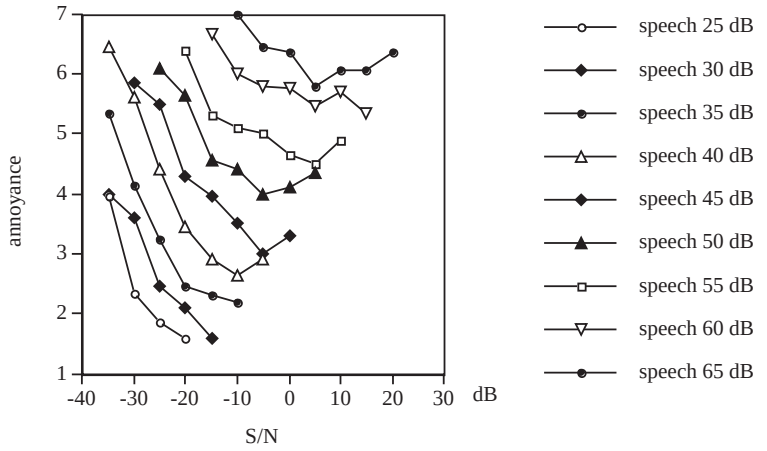

Fig. 5. Relation between C/N and annoyance of the combination of compartment noise and conversation. Keys are the same as in Fig. 4.

higher than 35 dB. There was a tendency that the annoyance increased as C/N increased in some conditions. This means that the combination of the compartment noise and the conversation was judged less annoying with high level of the compartment noise than with low level. This result suggests that there exists an optimum level of compartment noise taking the level of conversation into consideration.

4. Experiment 3

4.1. Stimuli

The same 57 combinations of compartment noise and conversation used in Experiment 2 were used in Experiment 3. These sounds were presented with the same equipment as in Experiment 2.

4.2. Procedure

The subjects were instructed to suppose that he/she was seated in a compartment of Shinkansen and heard the conversation of the neighboring passengers. They were asked to judge the disturbance of the conversation using 5 categories from not disturbing at all to very disturbing. The same 20 subjects as in Experiment 2 participated in Experiment 3.

4.3. Results

The judgments by 20 subjects were averaged. The relation between the level of conversation and the disturbance judgment is shown in Fig. 6. It is clearly seen that even if the level of conversation is equal, the disturbance differs according to the level of compartment noise. The lower the level of

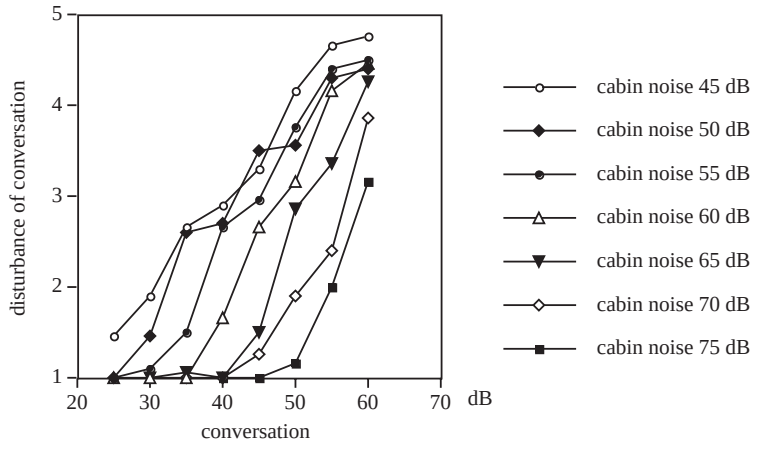

Fig. 6. Relation between L_{Aeq} of conversation and disturbance of conversation. Open circles, filled diamonds, filled circles, open triangles, filled triangles, open diamonds, and filled squares indicate the conditions of compartment noises of 45, 50, 55, 60, 65, 70 and 75 dB respectively.

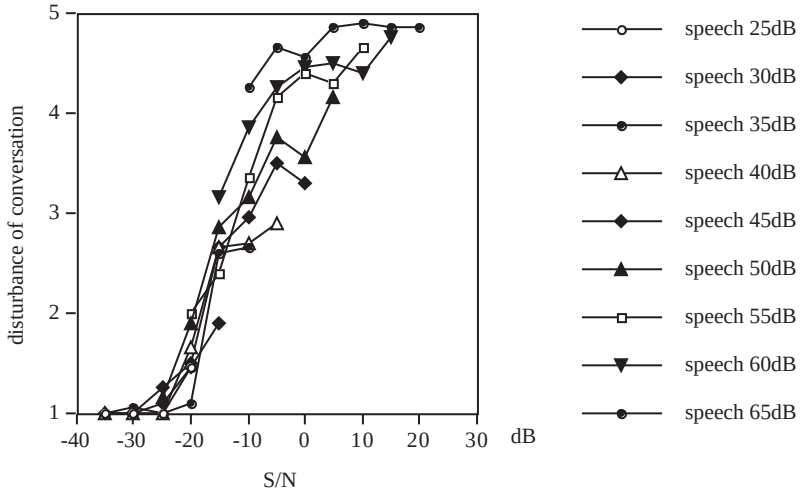

Fig. 7. Relation between C/N and the disturbance of conversation. Keys are the same as in Fig. 4.

compartment noise became, the more disturbing the conversation was judged. This suggests that the compartment noise helps to reduce the disturbance of conversation.

The disturbance of conversation is plotted against C/N in Fig. 7. Fairly high correlation can be seen between them. The coefficient of correlation is 0.936. That is, as larger the C/N became, the more disturbing the conversation was judged. At the same time, there are some deviations. The conversation was judged as being disturbing regardless of the level of compartment noise when the level of conversation became high.

Table 3
Optimum level of compartment noise obtained in Experiment 2

Level of conversation	Optimum level of compartment noise
25	—
30	—
35	—
40	50
45	50
50	55
55	50
60	55*
65	60

—, No optimum level could be obtained; * the value where the slope changed from negative to positive for the first time.

5. Discussion

Taking the points where the annoyance was the lowest in each level of conversation as the optimum condition (see Fig. 5), the values of the compartment noise were examined. They are listed in Table 3. The optimum level of the compartment noise was fairly constant, from 50 to 60 dBA, regardless of the level of conversation.

It was found in Experiment 1 that the lower the compartment noise of Shinkansen, the less annoying it was. However, the conversation of other passengers became more annoying in a quieter environment. This fact was confirmed in Experiment 2.

The disturbance of the conversation increased as C/N increased. However, the conversation was judged as being disturbing regardless of the level of compartment noise when the level of conversation became high.

These results further suggest that there exists an optimum level of the compartment noise. The necessary requirements of the optimum compartment noise may be as follows:

1. The compartment noise itself is not annoying.
2. The compartment noise contributes to decrease the adverse effect of conversation, which is meaningful.

Generally, the annoyance of the combination of the compartment noise and the conversation increased as C/N decreased. Also, the annoyance of the combined sounds increased as the level of conversation increased. At the same time, there was a tendency that annoyance increased as C/N increased in some conditions. This suggests that there exists an optimum level of compartment noise taking the level of conversation into consideration. The optimum level was between 50 and 60 dBA as far as the results of this experiments were concerned.

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