Acoust. Sci. & Tech. **26**, 3 (2005)

PAPER

Railway bonus for noise disturbance in laboratory settings

Hui Ma[1,*] and Takashi Yano[2,†]

[1]*Graduate School of Science and Technology, Kumamoto University, Kurokami 2–39–1, Kumamoto, 860–8555 Japan*
[2]*Department of Architecture and Civil Engineering, Faculty of Engineering, Kumamoto University, Kurokami 2–39–1, Kumamoto, 860–8555 Japan*

(*Received 12 December 2003, Accepted for publication 12 October 2004*)

Abstract: Disturbance caused by railway and road traffic noises in simulated outdoor (noise levels at $L_{\mathrm{Aeq,\,6\,min}}$ of 55, 65 and 75 dB) and indoor (noise levels at $L_{\mathrm{Aeq,\,6\,min}}$ of 35, 45 and 55 dB) conditions was investigated in laboratory settings. In each experiment, 30 Japanese and 30 Chinese subjects were requested to perform auditory (listening) and non-auditory (calculation) tasks while each noise was presented for 6 minutes, and then to assess the disturbance caused by the noises using 5-point verbal scales constructed by the ICBEN method. The results showed that though some railway bonus caused by noise masking did exist for auditory task in the outdoor conditions, no railway bonus was found for the other situations. On the contrary, in the indoor conditions, railway noise was evaluated to be a little more disturbing to the activities than road traffic noise by the subjects in most cases. Though the Japanese subjects appeared to be more sensitive to noises than the Chinese subjects, no systematic difference was found between the two subject groups.

Keywords: Railway bonus, Noise disturbance, Auditory task, Non-auditory task

PACS number: 43.50.−x [DOI: 10.1250/ast.26.258]

1. INTRODUCTION

Railway bonus is a reflection of the findings, that at the same noise level railway noise is evaluated to be less annoying than road traffic noise, in the noise regulations of certain European countries. Former social surveys on community responses to transportation noises have proved railway bonus apparently in Euro-American countries [1,2]. Fastl *et al.* [3] also found support for the railway bonus in a laboratory study of the loudness of railway and road traffic noises using responses from Japanese and German subjects. However, recent social surveys conducted in Japan [4,5] have shown different results. Kaku *et al.* [4] reported that although the dose-response relationships for conventional railway and road traffic noises were almost the same, the conventional railway noise was slightly more annoying. Yano *et al.* [5] supported Kaku's finding and showed that railway noise interfered with auditory task significantly more than did road traffic noise.

The present study investigated whether the degree of activity interference were different between railway and road traffic noises. It focused on exploring whether railway bonus existed or not when noise disturbance was used as a psychological attribute in laboratory settings. Considering that subjects' responses to railway and road traffic noises may differ between in outdoor and indoor conditions, two separate similar experiments were conducted: In Experiment I higher noise levels, which were realistic noise levels in outdoor conditions, were used while in Experiment II lower noise levels, which were realistic noise levels in indoor conditions, were used. Except this difference, the two experiments were executed by almost the same method. The following parameters were considered in both experiments: 1) noise sources (railway and road traffic noises); 2) noise levels ($L_{\mathrm{Aeq,\,6\,min}} = 55$, 65 and 75 dB for Experiment I; $L_{\mathrm{Aeq,\,6\,min}} = 35$, 45 and 55 dB for Experiment II); 3) different tasks, auditory (listening) and non-auditory (calculation); and 4) different subjects, Japanese and Chinese. To avoid the influence of situational bias on noise disturbance evaluation, both Japanese and Chinese subjects were kept at almost the same concentration level and comparable standardized verbal scales constructed according to the ICBEN method [6] were used.

2. METHOD

2.1. Subjects

Experiment I: Thirty Japanese from 22 to 35 years of

*e-mail: mahui73@hotmail.com
†e-mail: yano@gpo.kumamoto-u.ac.jp

age and 30 Chinese from 22 to 43 years of age participated. The number of the male and female subjects was 14 and 16 for the Japanese, and 15 and 15 for the Chinese, respectively.

Experiment II: The subjects were 30 Japanese from 20 to 25 years of age and 30 Chinese from 23 to 42 years of age. They were different from those in Experiment I. The ratio of male to female was kept at 1:1 for both the Japanese and the Chinese subjects.

Most of the subjects who participated in the present study were graduate students of Kumamoto University, Japan. In both experiments, the subjects were divided into 10 Japanese groups and 10 Chinese groups, which means that three subjects executed the experiments together.

2.2. Test Sounds

Experiment I: Six kinds of noise, (three railway and three road traffic noises), were used. The railway noise was recorded along a JR railway line in Kumamoto, Japan. The noise of each train passage was recorded simultaneously at 10 m and 80 m distance perpendicular from the railway. Three 6-minute railway noises consisting of five passages each were prepared from the two railway recordings according to the previous experience [7]. The equivalent continuous A-weighted sound pressure levels ($L_{\mathrm{Aeq,\,6\,min}}$) of the three noises were 55, 65 and 75 dB, which were realistic noise levels in outdoor conditions. Road traffic noises from a commercial CD, which were recorded at 5 m and 25 m distance perpendicular from the road shoulder, were used to minimize the influence of other sounds caused by birds or insects. As well as the railway noises, three 6-minute road traffic noises with $L_{\mathrm{Aeq,\,6\,min}}$ of 55, 65 and 75 dB were prepared.

The frequency spectrum patterns for each noise source were similar as shown in Fig. 1. However, the mid-frequency components of railway noise were of higher intensity than those of the road traffic noise. Figure 2 shows the time patterns of railway and road traffic noises used in Experiment I. In the experiment, the time patterns for railway noise were kept almost same.

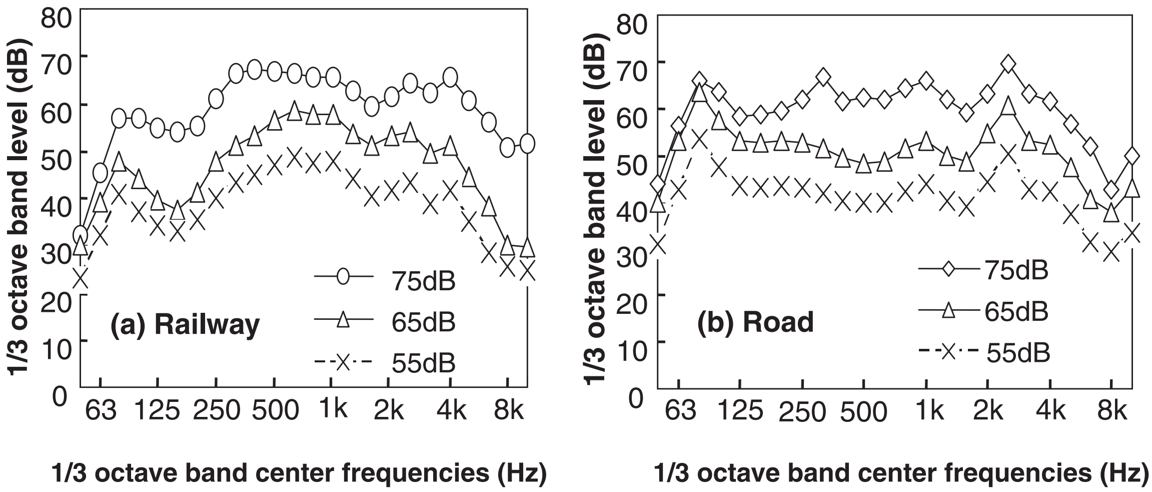

Fig. 1 Spectra of noise stimuli used in Experiment I.

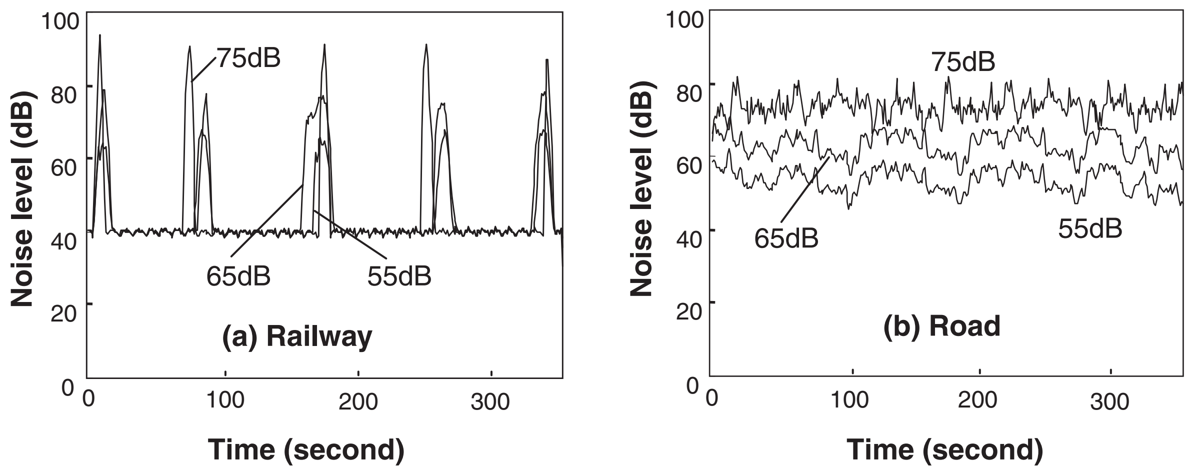

Fig. 2 Time patterns for the noise stimuli used in Experiment I.

Experiment II: The noise stimuli in this experiment were obtained by weighting the stimuli of Experiment I through a "house filter" as shown in Fig. 3. This figure shows the relative frequency weighting, referred to the response at 1 kHz, of sound transmitted through the typical house window (single pane) of Kyushu in real-life conditions [5]. After being weighted by the house filter, the noise stimuli in Experiment I were decreased by 20 dB of overall A-weighted sound pressure level by adjusting the volume of amplifier, and then three railway noises and three road traffic noises with $L_{\mathrm{Aeq,\,6\,min}}$ of 35, 45 and 55 dB were prepared, respectively. These are realistic noise levels in indoor conditions. Figures 4 and 5 show the spectrum and time patterns of noise stimuli used in Experiment II, respectively.

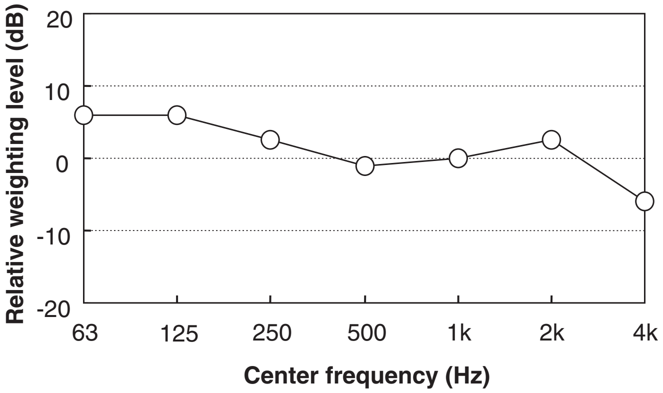

Fig. 3 The house filter used in Experiment II.

2.3. Tasks

Both the two experiments consisted of the same auditory and non-auditory tasks. In the auditory task that simulated conversation in daily life, the subjects were asked to listen to statements read out by a Japanese or Chinese female announcer and then judge whether the statements were reasonable or not. In order to avoid the

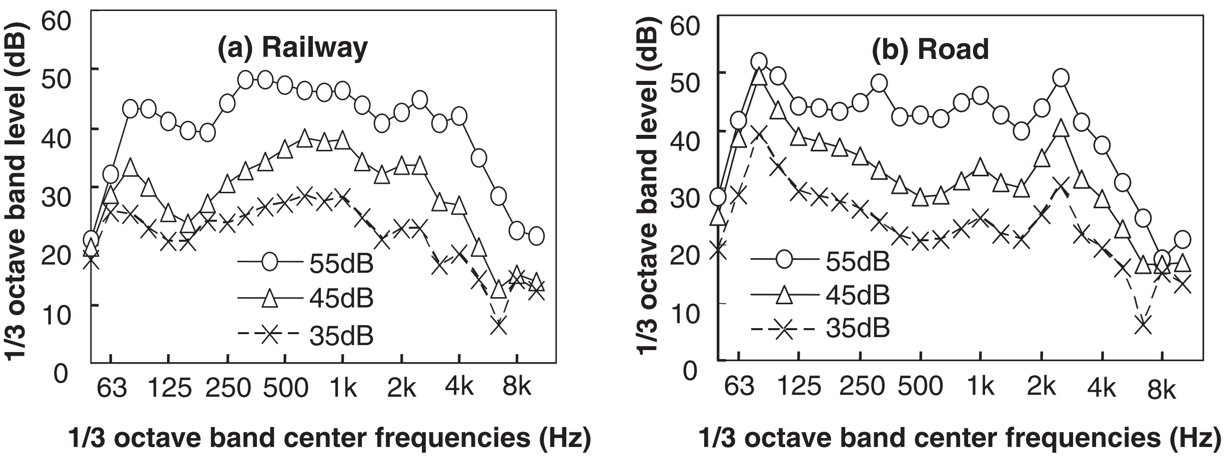

Fig. 4 Spectra of noise stimuli used in Experiment II.

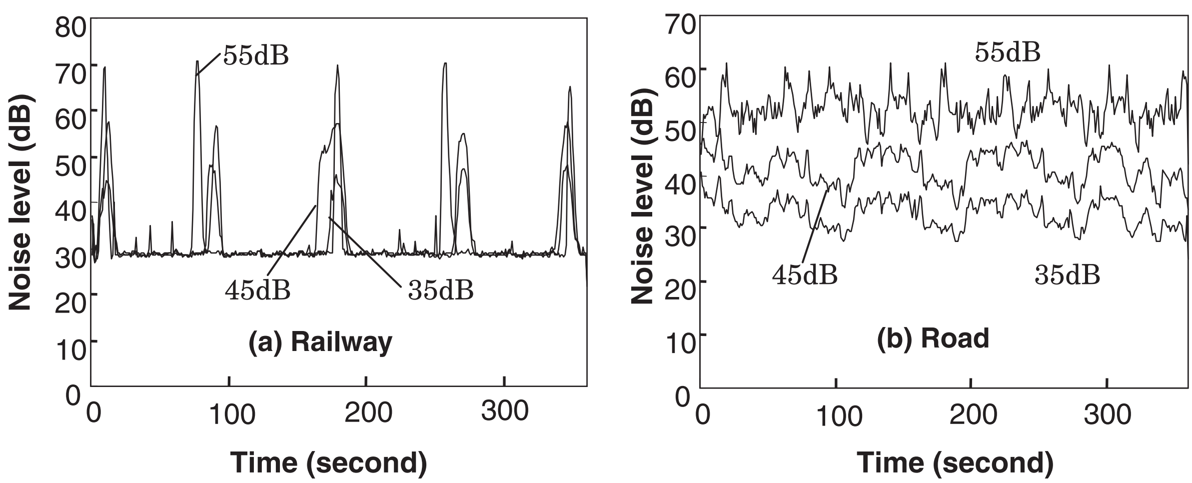

Fig. 5 Time patterns for the noise stimuli used in Experiment II.

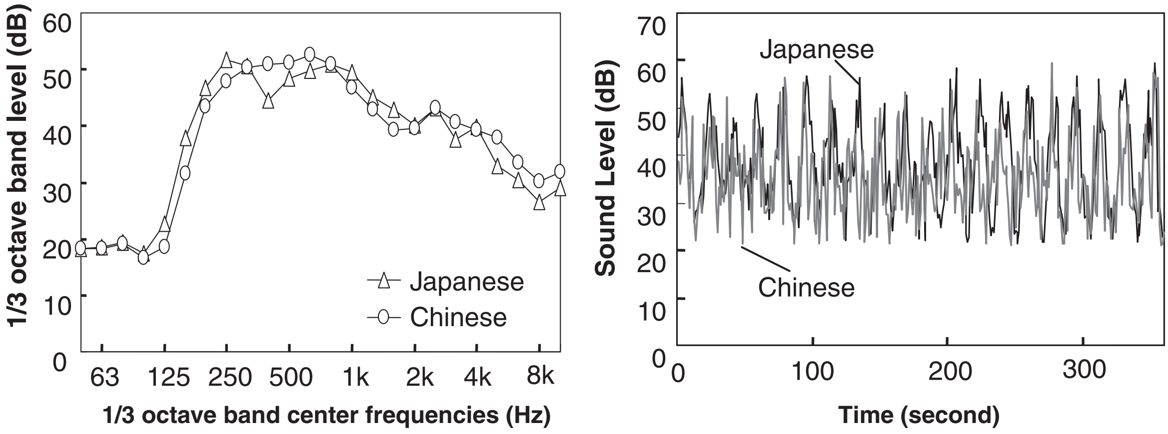

Fig. 6 Spectrum and time patterns for speech signals.

influence of the subjects' knowledge background and logic ability, all the statements were designed as simple as possible. If the subjects could hear the statements clearly, they would give the correct answers easily. The speech signals were recorded in an anechoic room and the sound levels of the whole Japanese and Chinese speech were set around 55 dB $L_{\mathrm{Aeq,\,6\,min}}$. As for the sound level of the speech signal used in each subsection task, it varied slightly around 55 dB $L_{\mathrm{Aeq,\,6\,min}}$. Figure 6 shows the spectrum and time patterns for Japanese and Chinese speech signals. From Fig. 6 it is shown that both Japanese and Chinese speech signals have the similar spectrum and time patterns. In each experiment, there were six auditory task subsections with 20 statements each. After each 6-minute reproduction of 20 statements, the subjects were asked to evaluate the noise disturbance using a 5-point verbal scale.

In the calculation task, the subjects were required to fill in the blanks in some statistical forms on the achievements of a basketball team and its players, using simple calculations. This calculation task simulates the usual intelligence activities in daily life. There were six forms prepared for the each formal experiment and the time taken for each form was fixed at 6 minutes. After the 6 minutes, the noise stopped and the subjects were asked to evaluate the disturbance caused by the noise using the 5-point verbal scale.

In each experiment, the order of the six subsections of each task was the same for all subjects and the noise stimulus reproduced during each task subsection was arranged according to Latin square design.

2.4. Scale

The comparable verbal scales used in rating disturbance were "mattaku. . .nai," "sorehodo. . .nai," "tasho," "daibu" and "hijoni" in Japanese and "yi dian ye bu," "hao xiang you dian," "bi jiao," "xiang dang" and "te bie" in Chinese. These verbal scales were constructed by the ICBEN method [6] and are equivalent to the English scale, "not at all," "slightly," "moderately," "very" and "extremely."

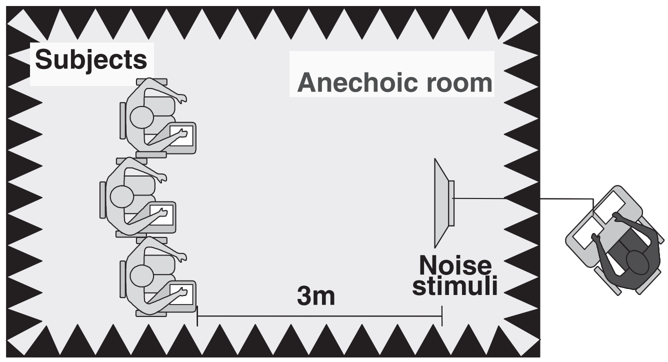

Fig. 7 The experiment settings.

2.5. Experiment Settings

Figure 7 shows the experiment settings. All the experiments were conducted in an anechoic room. Three subjects participated in the experiment together. Both the noise stimuli and the speech signals were fed to subjects via a loudspeaker. The distance between subjects and the loudspeaker was around 3 meters. Considering the potential masking effects of noise stimuli on speech signals, a display was put on the loudspeaker to show the number of the statements in the auditory task.

2.6. Procedure

The procedure for each experiment was as follows: 1) the subjects were given instructions which outlined the purpose and procedure of the experiment; 2) subjects sat in three immovable chairs which were located on a radius of 3 m from the loudspeaker and with a distance of 0.8 m between them to keep minimize discrepancies in sound level at each chair; 3) after a few practice trials, subjects were instructed to perform a listening or a calculation task while the 6-minute noise would be given; and 4) when the noise stopped, subjects evaluated the disturbance caused by the noise using the 5-point verbal scale. The interval between Experiment I and II was six months.

3. RESULTS

3.1. Analysis of Variance

There are four factors that might have a potential influence on noise disturbance evaluation in the present study: noise sources, noise levels, tasks and subjects. Tables 1 and 2 show the results of analysis of variance obtained in Experiment I and II, respectively. If only the effects of single factors were considered, noise levels had the best relationship to disturbance evaluation in both experiments. Tasks had a certain effect on disturbance evaluation when the noise stimuli were at higher noise levels while they had no influence on disturbance evaluation when noise stimuli were at lower noise levels. As for the interaction between two factors, they have stronger effect on disturbance evaluation in the outdoor conditions than in the indoor conditions.

Table 1 Analysis of variance in Experiment I.

Source	Type III sum of squares	df	Mean square	F	Significance
Corrected Model	457.24	14	32.66	43.97	0.00
Intercept	6,426.11	1	6,426.11	8,651.58	0.00
SOURCE	5.87	1	5.87	7.90	0.01
LEVEL	340.56	2	170.28	229.25	0.00
TASK	15.90	1	15.90	21.41	0.00
SUBJECT	10.04	1	10.04	13.51	0.00
SOURCE* LEVEL	15.70	2	7.85	10.57	0.00
SOURCE* TASK	23.11	1	23.11	31.12	0.00
SOURCE* SUBJECT	5.17	1	5.17	6.96	0.01
LEVEL* TASK	33.85	2	16.93	22.79	0.00
LEVEL* SUBJECT	1.87	2	0.94	1.26	0.29
TASK* SUBJECT	5.17	1	5.17	6.96	0.01
Error	523.65	705	0.74		
Total	7,407.00	720			
Corrected Total	980.89	719			

(df: degree of freedom)

Table 2 Analysis of variance in Experiment II.

Source	Type III sum of squares	df	Mean square	F	Significance
Corrected Model	297.96	14	21.28	35.75	0.00
Intercept	3,582.27	1	3,582.27	6,016.44	0.00
SOURCE	7.61	1	7.61	12.77	0.00
LEVEL	244.84	2	122.42	205.61	0.00
TASK	0.94	1	0.94	1.56	0.21
SUBJECT	12.80	1	12.80	21.50	0.00
SOURCE* LEVEL	0.08	2	0.04	0.07	0.94
SOURCE* TASK	0.27	1	0.27	0.46	0.50
SOURCE* SUBJECT	3.76	1	3.76	6.31	0.01
LEVEL* TASK	23.88	2	11.94	20.05	0.00
LEVEL* SUBJECT	3.70	2	1.85	3.11	0.05
TASK* SUBJECT	0.09	1	0.09	0.15	0.70
Error	419.77	705	0.60		
Total	4,300.000	720			
Corrected Total	717.73	719			

(df: degree of freedom)

3.2. Comparison of Dose-Response Relationships between Railway and Road Traffic Noises

Figure 8 shows the difference in subjective disturbance evaluation between railway and road traffic noises in both the outdoor and the indoor conditions. Under the outdoor conditions, road traffic noise was evaluated by the two subject groups to be more disturbing than railway noise for auditory task particularly when noise level was at 75 dB $L_{\mathrm{Aeq,\,6\,min}}$. However, in the non-auditory task there was no difference between these two noises for the Chinese subjects and railway noise was evaluated a little more disturbing than road traffic noise by the Japanese subjects. The difference in disturbance between railway and road traffic noises for auditory task was significant at 1% level at 75 dB $L_{\mathrm{Aeq,\,6\,min}}$ by Tukey's multiple comparison test. In the indoor conditions, railway and road traffic noises did not differ significantly in disturbance evaluation. Particularly, railway noise was evaluated to be a little more disturbing than road traffic noise to their auditory task by the two subject groups. This is consistent with the findings reported in the previous social survey studies [2,5] that listening disturbance caused by railway noise is greater than that caused by road traffic noise.

These results above suggested that railway bonus only existed for the auditory task in the outdoor conditions. Figure 9 shows the relative cumulative frequency of sound pressure levels of the different noises in the outdoor conditions. Compared with railway noise, road traffic noise usually has relatively high sound pressure level components because of its temporally continuous characteristic, though railway noise contains a few short-term higher level events. Considering that the sound level of speech signals was set around $L_{\mathrm{Aeq,\,6\,min}}$ of 55 dB, road traffic noise had a stronger masking effect on the speech signal than railway noise because of the sound level distributions.

Figures 10 and 11 show the relative cumulative frequencies of Articulation Index and Intelligibility Index for speech signals, respectively. In order to calculate the Articulation Index and Intelligibility Index, the followings were hypothesized: 1) The frequency characteristics of the noises were constant as shown in Fig. 1 whatever the sound levels were; 2) Though the spectrum of the male voice is used in the original procedure to calculate the Articulation Index [8], the spectra of females' voice as shown in Fig. 6 might be used here; 3) The relationship between Articu-

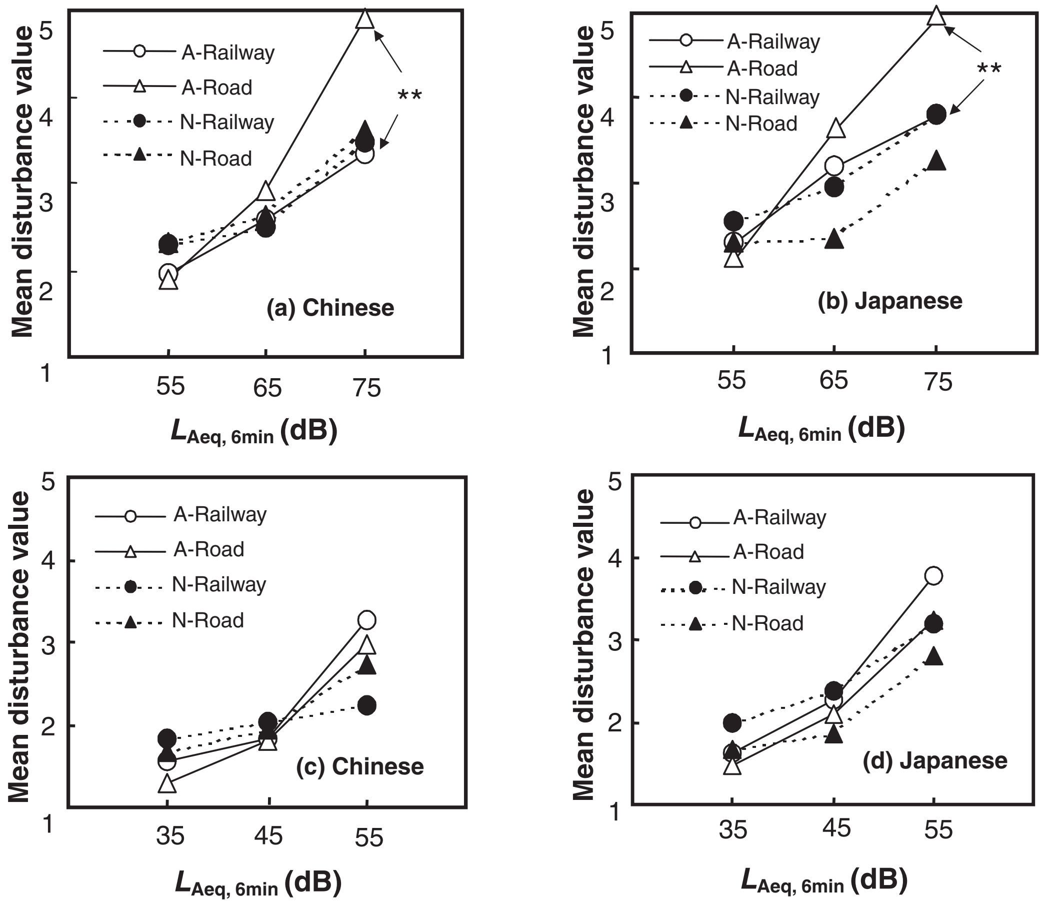

Fig. 8 Comparison of dose-response relationships between railway and road traffic noises (the upper two figures are results in Experiment I; the lower ones are results in Experiment II; "**" means railway and road traffic noises differed significantly at 1% level; "A-Railway," "A-Road," "N-Railway," and "N-Road" show auditory task in railway noise condition, auditory task in road traffic noise condition, non-auditory task in railway noise condition and non-auditory task in road traffic noise condition, respectively).

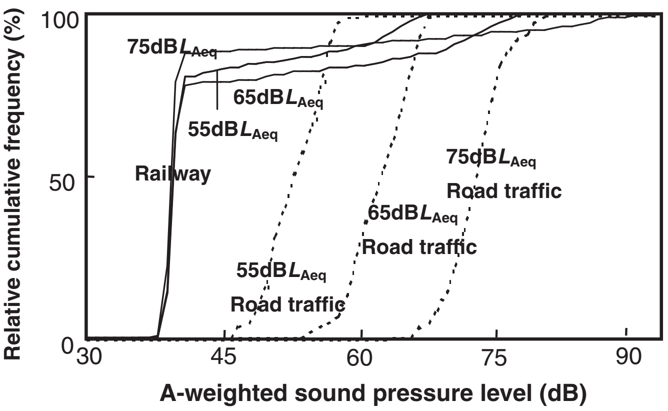

Fig. 9 Relative cumulative frequency of sound pressure level of noises used in Experiment I (solid lines: railway noises; dashed lines: road traffic noises).

lation Index and Intelligibility Index in Japanese [9] were applicable to Chinese. Based on these, the Articulation Index was calculated for percentile noise levels, L_{95}, L_{90}, L_{50}, L_{10} and L_5, and then the curves were shown. From Fig. 10 it is shown that there was a significant difference in the value of Articulation Index for speech signals between the railway and road traffic noise conditions whatever noise level was. The duration below the Articulation Index of 0.8 was around 40% in railway noise and 100% in road traffic noise. Thus the Articulation Index was better in railway noise condition than in road traffic noise condition.

However, according to the relationship between Articulation Index and Intelligibility Index [9], the Intelligibility Index of speech can reach 90% when the Articulation Index is just around 0.3. Figure 11 shows the Intelligibility Index of Japanese and Chinese speech signals in Experiment I. In Fig. 11(d) the relative cumulative frequency curve was overlapped by the ordinate. When the noise level was at 55 dB $L_{Aeq, 6\,min}$, there was no significant difference in Intelligibility Index between railway and road traffic noise conditions. For example, the durations below the Intelligibility Index of 0.9 are less than 10% and the speech signals are almost intelligible. Though the Intelligibility Index in road traffic noise condition was apparently lower than that in railway noise condition at 65 dB $L_{Aeq, 6\,min}$, the

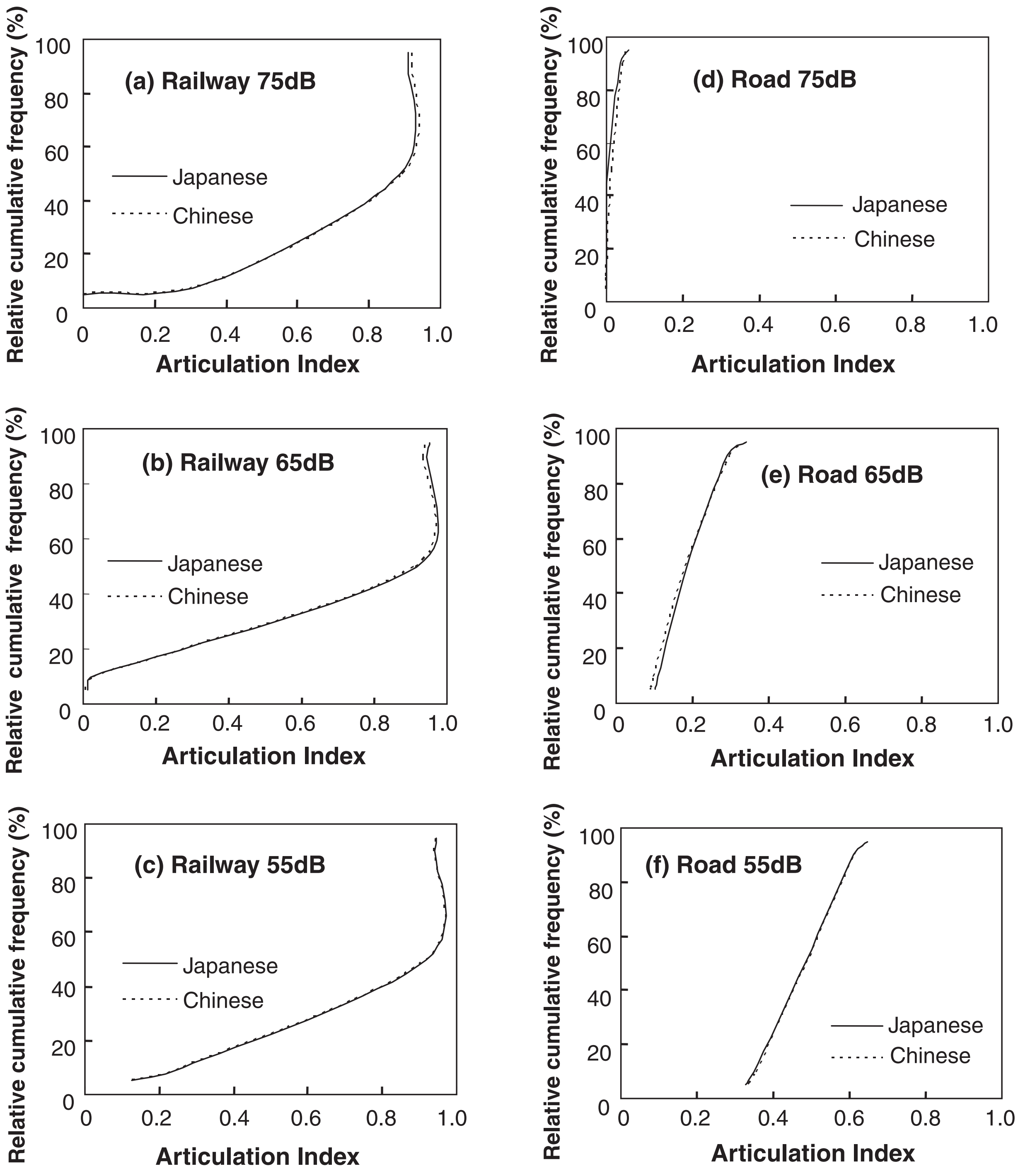

Fig. 10 Relative cumulative frequency of Articulation Index of Japanese and Chinese speech signals in Experiment I.

Intelligibility Index can reach 50% in more than half of the duration and that could assume the understanding of the auditory task. At 75 dB $L_{\mathrm{Aeq,\,6\,min}}$ the Intelligibility Index for speech signals in road traffic noise condition was almost 0, whereas the Intelligibility Index in railway noise condition was about 90% in most of the duration.

Figure 12 shows how many statements the subjects reported that they could not hear in Experiment I. In this figure the decrement in hearing differed significantly between railway and road traffic noises when noise level was at 75 dB $L_{\mathrm{Aeq,\,6\,min}}$ and this could be another comparable indicator to demonstrate the difference in masking effect between railway and road traffic noises. All the results above suggest that the railway bonus found for the auditory task in the outdoor conditions was mainly caused by noise masking.

3.3. Comparison of Disturbance Evaluation between Japanese and Chinese Subjects

Under most of the conditions in both experiments, the

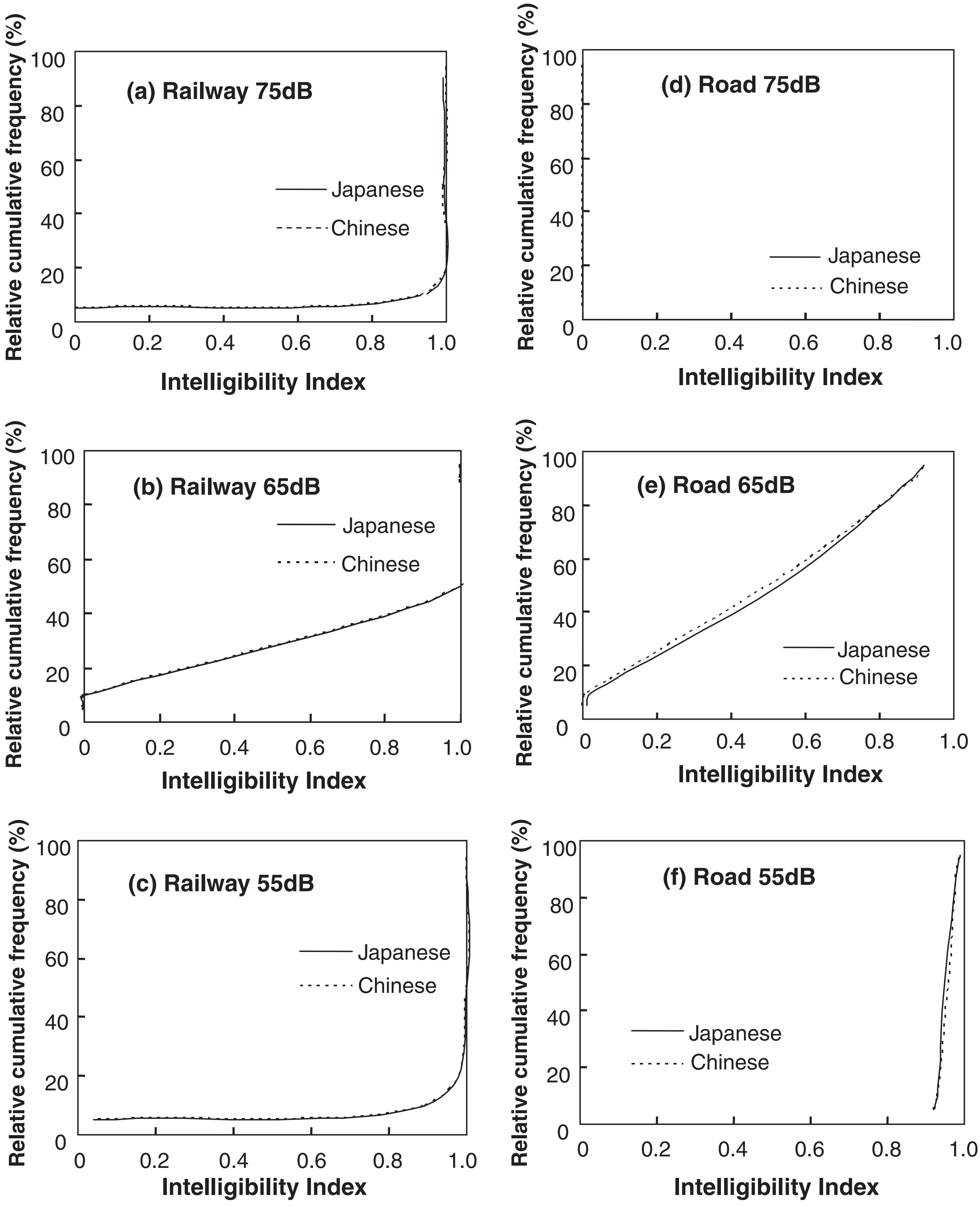

Fig. 11 Relative cumulative frequency of Intelligibility Index of Japanese and Chinese speech signals in Experiment I.

Japanese subjects tended to give greater disturbance evaluation to transportation noises than the Chinese subjects. However, through the statistical analysis no systematic difference was found in disturbance evaluation between the Japanese and Chinese subjects under both the outdoor and indoor conditions.

4. DISCUSSION

Though a certain railway bonus, which was mainly caused by noise masking, was found for the auditory task when the noise level was at 75 dB $L_{\mathrm{Aeq},\,6\,\mathrm{min}}$, no railway bonus was found under the other conditions of the present laboratory study. This is consistent with the results from

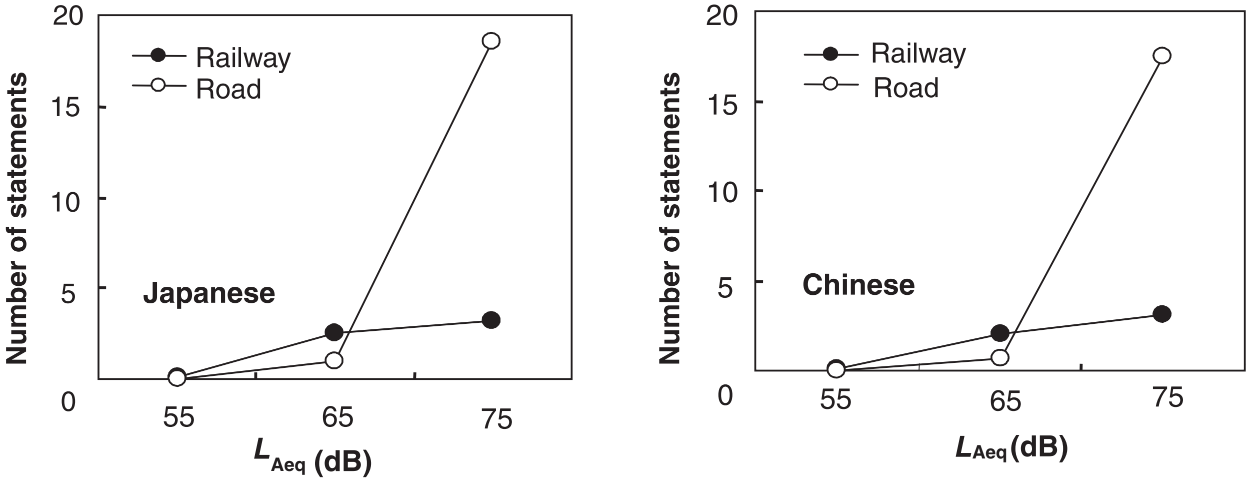

Fig. 12 The average number of the statements that subjects could not hear in Experiment I.

the social surveys conducted in Japan recently [4,5] and it seems to suggest that the dose-response relationships of railway and road traffic noises will not differ significantly if the noise sources do not bring direct inference such as masking to subjects' activities. In the present study, both Japanese and Chinese subjects appeared the similar response to railway and road traffic noises whatever the noise levels were higher or lower. Therefore, why railway bonus was found in the studies of Euro-American countries while no railway bonus was found in the social surveys conducted in Japan needs to find more rational reasons including the consideration of the cultural and social difference between two areas.

Among the four factors considered (noise sources, noise levels, tasks and subjects), noise levels affected the subjective disturbance evaluation as a stable factor in both the outdoor and the indoor conditions. The type of task had a certain effect on noise disturbance caused by road traffic noise when noise levels were higher while it had no influence on disturbance evaluation in the other conditions particularly in the lower noise level conditions. It was mainly because the auditory tasks were influenced more directly by the physical characteristics of noise stimuli than were the non-auditory tasks, particularly when noise stimuli were at high levels and had strong masking effects. Though other factors had little effect on disturbance evaluation, the interaction between two factors could make the subjects' response to railway and road traffic noises more complicated especially in the outdoor conditions.

5. CONCLUSION

No railway bonus was found in the present laboratory study, though railway noise was evaluated to be significantly less disturbing to subjects' auditory task when noise levels was at 75 dB $L_{\mathrm{Aeq},\,6\,\mathrm{min}}$ and this difference tended to increase with the increase of noise levels because of the different masking effects caused by railway and road traffic noises.

The results from the experiment in the indoor conditions were very similar to those of the recent social surveys conducted in Japan. Including social and cultural factors, further factors such as subjective attitude to transportation noises should be considered on the problem of railway bonus.

REFERENCES

[1] J. M. Fields and J. G. Walker, "Comparing the relationships between noise level and annoyance in different surveys: A railway noise vs. aircraft and road traffic comparison," *J. Sound Vib.*, **81**, 51–80 (1982).

[2] U. Moehler, "Community response to railway noise: A review of social surveys," *J. Sound Vib.*, **120**, 321–332 (1988).

[3] H. Fastl, S. Kuwano and S. Namba, "Assessing the railway bonus in laboratory studies," *J. Acoust. Soc. Jpn.* (*E*), **17**, 139–147 (1996).

[4] J. Kaku and I. Yamada, "The possibility of a bonus for evaluating railway noise in Japan," *J. Sound Vib.*, **193**, 445–450 (1996).

[5] T. Yano, T. Sato, K. Kawai and K. Kurosawa, "Comparison of community response to road traffic and railway noises," *J. Acoust. Soc. Jpn.* (*J*), **54**, 489–496 (1998).

[6] J. M. Fields, R. G. de Jong, T. Gjestland, I. H. Flindell, R. F. S. Job, S. Kurra, P. Lercher, M. Vallet, T. Yano, R. Guski, U. Felscher-Suhr and R. Schumer, "Standardized general-purpose noise reaction questions for community noise surveys: Research and a recommendation," *J. Sound Vib.*, **242**, 641–679 (2001).

[7] T. Yano and A. Kobayashi, "Disturbance caused by various fluctuating single noises and combined community noises," *Environ. Int.*, **16**, 567–574 (1990).

[8] American National Standards Institute, "Methods for the calculation of the Articulation Index," ANSI S3.5-1969 (1969).

[9] T. Miura and Z. Yamoguchi, "Perception and speech," in *Hearing and Speech* (*Chokaku to Onsei*), T. Miura, Ed. (Corona, Tokyo, 1980), Chap. 4, p. 413.