Analysis of non-acoustic effects on noise annoyance caused by the Shinkansen Railway

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The Shinkansen Railway system has greatly increased its transportation capacity since it was first constructed. However, this has led to increased noise and vibration by running trains, which has disturbed inhabitants of areas along the railway tracks. To preserve the environment of people living along Shinkansen tracks, and out of concern for their health, the Environmental Quality Standards for Shinkansen Super-express Railway Noise was promulgated in 1975. The standards state that noise shall be evaluated based on an energy-based metric: the energy mean value of the top 10 among 20 peak noise levels (L_{Amax}). Recently, environmental quality standards regarding other noises were amended. New noise metrics are L_{Aeq} for noises in general living and roadside areas and L_{dn} for aircraft noises. Therefore, new metrics to measure the noise annoyance will likely be discussed in the near future. Three separate social surveys on community responses to the Shinkansen Railway noise and vibration have been conducted in Kanagawa and Fukuoka Prefectures, and the City of Nagoya, respectively. We assembled the survey data and analyzed the dose-response curves of the Shinkansen Railway noise. In particular, we examined whether non-acoustic factors affected the noise annoyance caused by the Shinkansen Railway or not. The analyses demonstrated that there were synergetic effects of the distance from the railway and vibration level associated with each of the residences on the noise annoyance. In addition, we explored whether or not demographic factors and responses to living environments affected the noise annoyance. Of the above factors, it was found that only gender provided a significant effect on the noise annoyance.

Key words: Shinkansen Railway, Social survey, Noise and vibration, Annoyance, Non-acoustic effect

1. INTRODUCTION

The Shinkansen Railway system has greatly increased its transportation capacity since it opened in 1964. This has led to increased levels of noise, vibration and low frequency noise, which has disturbed people living along the railway line. To preserve their environments and to protect their health against the adverse effects, the Environmental Quality Standards for Shinkansen Super-express Railway Noise were introduced in 1975. These standards state that noise shall be evaluated based on the L_{Amax} value, which is a measure of the energy mean value of the top 10 of 20 peak noise levels.

Several social surveys have been conducted to evaluate community response to noise from the Shinkansen Railway. For example, Sone et al.[1] discussed the application of several noise indices to evaluate local inhabitants annoyance with noise. Subsequently, Tamura[2] indicated that people living along the Shinkansen Railway provide more a lower rating to outdoor quietness than those who were living along conventional railways. Yokoshima & Tamura[3] found that the inhabitants had more severe attitudes toward noise associated with the Shinkansen Railway than individuals exposed to road traffic or conventional railway noise. Furthermore, Yokoshima & Tamura[4] used covariance structure analysis to demonstrate that the Shinkansen Railway noise and vibration had a synergistic effect on annoyance. Yano et al.[5] and Sato et al.[6] suggested that there was an interactive effect between the Shinkansen Railway noise and vibration on annoyance.

Recently, the environmental quality standards regarding road traffic and aircraft noises have been amended in Japan. Therefore, re-analysis of dose-response relationships of the Shinkansen Railway noise is indispensable for the revision of the standards. Here, we assembled three separate social surveys on community response to the Shinkansen Railway noise and vibration in the Kanagawa and Fukuoka Prefectures, and the City of Nagoya, respectively. We analyzed the dose-response relationships of the Shinkansen Railway noise. In particular, we focused on non-acoustic factors (distance, vibration, demographic factors and living environment) affecting whether noise annoyance caused by the Shinkansen Railway or not.

2. SOCIAL SURVEY AND MEASUREMENT

The three surveys were conducted separately. Details regarding operations of the Shinkansen train and the surveys are shown in Table 1.

2.1 Kanagawa Survey

Questionnaires were distributed to inhabitants in detached and apartment houses within 100 m of the track. Each survey site that had an area of 100 m^2 was selected at random.

The questionnaire consisted of 10 items. Q1 examined the evaluations of each living environment on a 5-point verbal scale. Q7 was designed to measure the annoyance reactions to each noise source, including the Shinkansen Railway noise, using the following ICBEN verbal scale: not at all, slightly, moderately, very, and extremely (bothered).

After the social survey was completed, noise and vibration measurements were made to estimate the exposures associated with each respondent's residence on a site-by-site basis. At several points with different distance from the track, SLOW-peak noise level (L_{ASmax}) with each passing train was measured. The L_{Amax}, noise exposure, was calculated based on the method required by the Environmental Quality Standards. One or more distance reduction equations were formulated to describe the relationship between logarithmic distance and the L_{Amax}. The noise exposure for each respondent was then estimated based on a corresponding equation.

Similarly, peak vertical vibration level of each passing train was measured at the same point as the noise was measured using a vibration level meter. Vibration exposure (L_{Vmax}) was calculated from the mean value of the top half levels of the measurements (re 10^{-5} m/s^2). The L_{Vmax} was estimated using a corresponding formula between logarithmic distance and the L_{Vmax}.

2.2 Nagoya Survey

The Nagoya Survey was conducted at the sites where the government of the City of Nagoya conducted monitoring of the noise and ground vibration from the Shinkansen Railway in 2005. In a survey site, the situation of the sources and reductions of noise and vibration were considered to be similar. The L_{Amax} and L_{Vmax} values were estimated using each reduction curve with distance based on the measurements collected by the government

Survey notices were delivered to those surveyed in advance, before investigators visited the participant's houses and interviewed the inhabitants. The questionnaire consisted of 11 items covering reactions to noise and vibration. Q2 examined the evaluations of each living environment on a 5-point verbal scale. Q5 was designed to measure the annoyance reaction to each noise source, including the railway noise, on the ICBEN verbal scale.

2.3 Fukuoka Survey

This survey was designed to evaluate all detached houses within 150 m of the Shinkansen Railway. However, when no houses were located within the 150 m range, detached houses directly facing the railway up to a maximum distance of 680 m from the track were also included. Respondents from 20 to 75 years of age were randomly selected from a list of voters on a one-person-per-family basis.

The questionnaire consisted of 47 items that differed from those of other surveys. Q20 examined the evaluations of each living environment on a 5-point verbal scale. Q21 was designed to measure the annoyance reaction including the Shinkansen Railway noise, using the ICBEN verbal scale.

After the social survey was conducted, measurement was made. The L_{ASmax} was recorded at a reference point close to the track and at other points with different distances from the reference point. A logarithmic regression equation designed to evaluate noise reduction with distance was formulated based on the L_{ASmax}. The L_{Amax} values at each dwelling were obtained from the L_{Amax} at the reference point and the noise reduction calculated using the formula. The L_{Vmax} at each dwelling was estimated using a procedure similar to that used in the Kanagawa Survey. However, the number of respondents for which L_{Vmax} was determined was only 358.

Table 1 Details regarding the Shinkansen Railway and the surveys used in this study

Survey	Kanagawa Survey	Nagoya Survey	Fukuoka survey
Railway line	New Tokaido Line	New Tokaido Line	New Sanyo Line
Train series	Series 300, 500, 700	Series 300, 500, 700	Series 0, 100, 300, 500, 700
No. of passes	Slightly less than 300 trains	Slightly less than 300 trains	Slightly less than 200 trains
Survey method	Distribution by mail	Interview	Distribution by collection
No. of survey sites	98 sites	20 sites	4 sites
Survey range	Within 100 m of the track	Within 100 m of the track	Within 150 m of the track
Survey date	Oct. 2001, Sep. - Oct. 2002, Oct. 2003	Feb. - Mar. 2005	Apr. 2003
Sample Size	1784	300	1090
Housing type	Detached and Apartment houses	Detached house	Detached house
Respondents (%)	986 (55%)	175 (58%)	724 (66%)

3. RESULTS

Table 2 shows demographic and housing factors that were common to the three surveys. Data for the respondents living in detached houses were used in this paper. More than 40% of respondents were over-sixties and about 80% lived for more than 10 years. Figure 1 shows the average noise and vibration exposures at different distances. Prefixes of "K_", "N_" and "F_" indicate the Kanagawa, Nagoya and Fukuoka Surveys, respectively. The L_{Amax} value of the Fukuoka Survey had the highest level, followed by the Nagoya and Kanagawa Surveys. The L_{Vmax} value of the Kanagawa Survey was slightly higher than that of the Nagoya Survey. Furthermore, the Fukuoka Survey had the lowest vibration level among the three surveys, being approximately 8 dB lower than that of the Kanagawa Survey.

Table 2 Results of the demographic and dwelling data

Items	Categories	Frequency (%)
Gender	Female	941 (51.7%)
	Male	802 (48.3%)
Age	Under 30	111 (6.3%)
	Thirties	174 (9.8%)
	Forties	272 (15.4%)
	Fifties	446 (25.2%)
	Sixties	469 (26.5%)
	70 and over	297 (16.8%)
Occupation	Employee	748 (43.3%)
	Student	22 (1.2%)
	Housewife	477 (27.6%)
	Unemployed	408 (23.6%)
	Other	71 (4.1%)
Number of family	1	110 (6.3%)
	2	550 (31.5%)
	3	384 (22.0%)
	4	377 (21.6%)
	5	189 (10.8%)
	6 and over	136 (7.8%)
Length of residence	Less than 5 years	151 (8.6%)
	Less than 10 years	205 (11.6%)
	10 years or longer	1405 (79.8%)

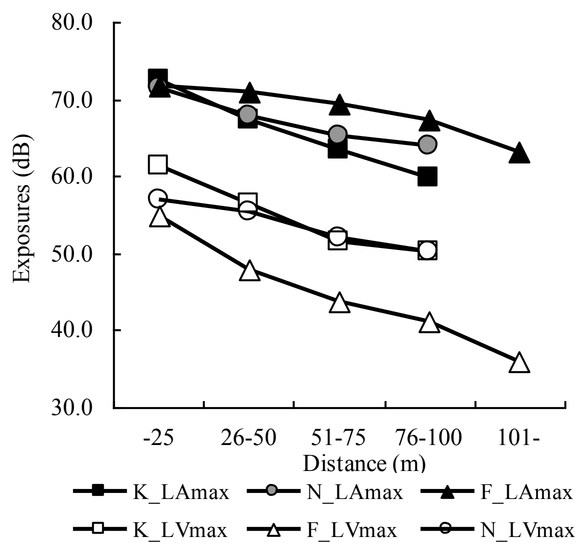

Figure 1 Averaged exposures according to the distance categories.

4. ANALYSIS

Non-acoustic factors, the L_{Vmax} and distance from the railway associated with each of the dwellings were examined to determine whether or not these contributed to the noise annoyance caused by the Shinkansen Railway. Figure 2 compares dose-annoyance relationships (L_{Amax} - %HA) between the distance categories (≤50m and >50m). The %HA was defined as the ratio of respondents who answered in the top "extremely" category in each exposure range. Likewise, Figure 3 compares dose-annoyance relationships (L_{Amax} - %HA), between the L_{Vmax} categories (≤50dB and >50dB). In addition, data of which sample size was under 20 in each L_{Amax} range did not plot for the both figures. At some L_{Amax} ranges, the differences in the %HA were significant at the 5% level for the distance. Furthermore, the differences in the L_{Vmax} were also found in some L_{Amax} ranges. Since the L_{Vmax} is related to the distance, these figures confirm that simultaneous exposure of the vibration to the respondents brings about a synergetic effect on the noise annoyance.

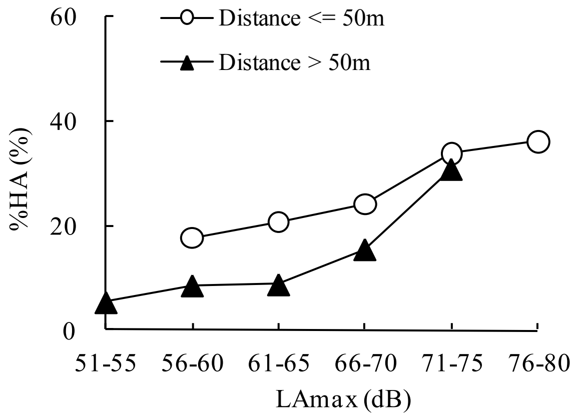

Figure 2 Comparison of the relationship between noise exposure and annoyance level sorted by distance categories.

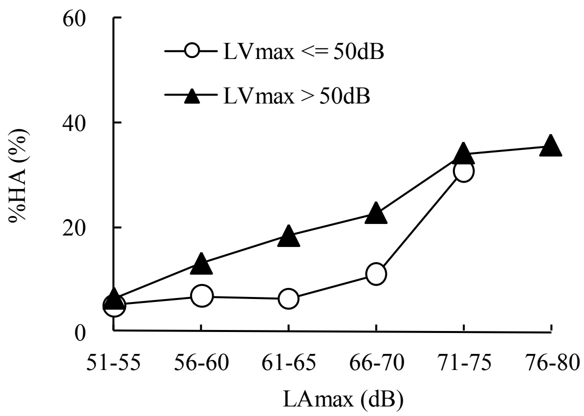

Figure 3 Comparison of the relationship between noise exposure and annoyance level sorted by vibration level categories.

Moreover, we examined a synergetic effect of vibration on the noise annoyance, using nominal logistic regression analysis. Two annoyance reactions, "highly annoyed" (HA) and "rather annoyed" (RA) reactions, were used for the objective variables. For the HA reaction, "extremely" and other responses to the annoyance were converted into 1 and 0, respectively. As for the RA reaction, the top two and other responses were categorized into the dummy variable. L_{Amax} and L_{Vmax} were set for the explanatory variables. The analysis for the HA reaction indicated that both coefficients of L_{Amax} and L_{Vmax} were significant at the 5% level. The similar effect was obtained for the RA reaction. Therefore, L_{Vmax} has a synergetic effect on the noise annoyance.

Next, effects of demographic factors on the noise annoyance were discussed. Figure 4 compares dose-annoyance relationships (L_{Amax} - %RA) between the genders. The %RA was defined as the respondent ratio of the RA reactions. This figure indicates little difference among the genders. Other demographic factors, age, occupation, number of family and length of residence, indicated little difference.

Then, the effect of demographic factors was reanalyzed including the effect of vibration. Figure 5 compares dose-annoyance relationships (L_{Amax} - %RA) between the genders sorted by vibration level categories. For $L_{Vmax} \leq$ 50dB, the %RA for female was higher than that for male. For $L_{Vmax} >$ 50dB, on the other hand, there was not so much of a difference. Subsequently, we applied nominal logistic regression analysis again. The objective and explanatory variables were used for the foregoing noise annoyance reactions. L_{Amax}, L_{Vmax} and each demographic factor were assigned to explanatory variables. These analyses demonstrated only significant effect of the gender on the RA reaction at the 5% level. These suggest that gender has an effect on the noise annoyance

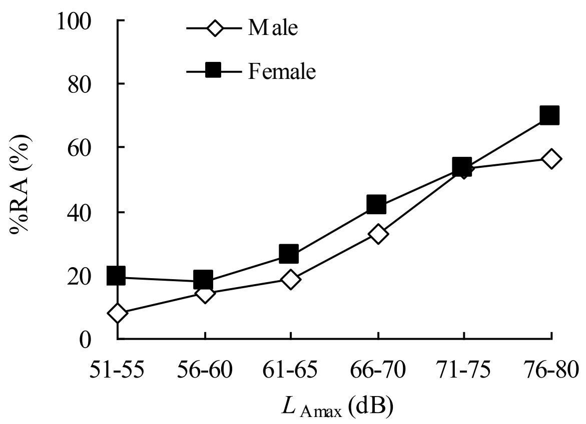

Figure 4 Comparison of the relationship between noise exposure and annoyance reaction between the genders.

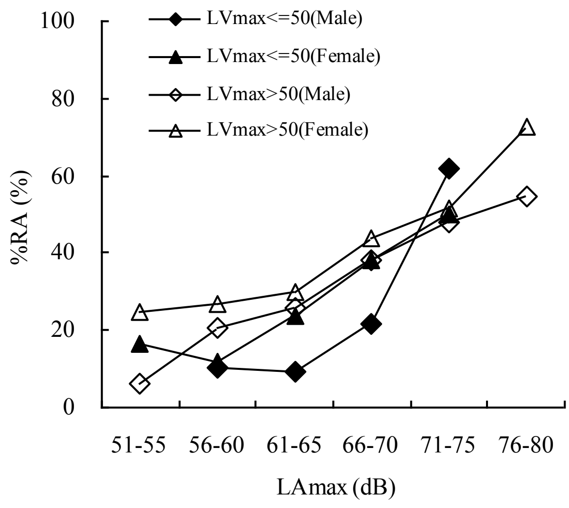

Figure 5 Comparison of the noise annoyance reaction between the genders sorted by vibration level categories.

Finally, we examined the responses to living environments affected whether the noise annoyance or not. The living environments, which were obtained from the three surveys, were as follows: natural/green, air pollution, shopping access, and traffic access. The effect was also investigated in the similar method as the demographic factors. The analysis indicated that the four responses had no significant effects on the annoyance reactions.

5. CONCLUSIONS

We examined whether or not non-acoustic factors affected the noise annoyance caused by the Shinkansen Railway. Vibration level, which is related to the distance from the railway, associated with each of respondent' residences have a synergetic effect on the noise annoyance. In addition, we clarified that only gender of the demographic factors has a significant effect on the noise annoyance.

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