Effects of the railway category and noise on vibration annoyance

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ABSTRACT

Railway-induced noise and vibration in buildings cause adverse physiological and psychological effects on people in urban districts. Annoyance due to noise and vibration from railway has been investigated by using the methods of socio-acoustic surveys and subjective evaluation experiments. Japanese previous surveys revealed that community response to noise differed according to the following railway categories: the Shinkansen and conventional railways. Inhabitants living along the Shinkansen railway have negative attitudes to noise from the Shinkansen railway and do not recognize the necessity of the noise source. Therefore, the Shinkansen railway leads to greater noise annoyance than conventional railway. In addition, many researchers have addressed the mutual effect of noise and vibration produced by trains on annoyance. However, quantitative method to evaluate the mutual effect has not been fully established. Applying a multiple logistic regression analysis to the Japanese datasets, the authors tried to provide quantitatively the effects of railway categories and noise on vibration annoyance. Based on the obtained results, we discuss the effects of railway noise and vibrations on annoyance.

Introduction

"ENVIRONMENTAL NOISE GUIDELINES for the European Region" [1], published in October 2018, recommended exposure levels for environmental noise to protect population health. For average noise exposure, the Guideline Development Group strongly recommends reducing noise levels produced by railway traffic below 54 dB L_{den}, as railway noise above this level is associated with adverse health effects. However, the guidelines excluded noise induced by high-speed railway trains. Using the Socio-acoustic Survey Data Archive (SASDA) in Japan [2], Yokoshima et al. [3] and Ota et al. [4] revealed higher annoyance due to noise from the Shinkansen railway than that from conventional railway.

Several socio-acoustic surveys were performed to clarify the factors of difference in community response between conventional and high-speed railways. Tamura [5] compared community response to general noise in residential areas along the Shinkansen and conventional railways in Japan. He pointed out that inhabitants living along the Shinkansen railway had negative attitudes to the noise source and did not recognize the necessity for the noise source. Subsequently, Yokoshima et al. [6-8] confirmed the combined effects of noise and ground-borne vibration from the Shinkansen railway on annoyance. These papers indicated that annoyance due to vibration increased with an increase not only in vibration exposure but also in noise exposure. Focusing on the combined effects of noise and vibration on annoyance, Peris et al. [9] showed that a response curve of combined noise and vibration from conventional railway would give a better understanding of the real effects on annoyance. This paper suggested that neglecting noise when assessing the vibration annoyance would result in an underestimation of the percentage highly annoyed people (%HA) by ground-borne vibration.

In addition to socio-acoustic surveys, laboratory-based experiments have been performed to examine combined effect of noise and vibration on human response. Lee et al. [10] investigated the combined effect of noise and vibration on annoyance in buildings during the passage of high-speed train with recorded train noise and 20Hz vibration. They found that vibration did not influence noise annoyance rating, but that the total annoyance caused by the combined noise and vibration was considerably greater than the annoyance caused by noise alone. Morihara et al. [11] carried out an experimental study to examine the combined effect of high-speed railway noise and vibration on activity disturbances, using noise and vibrations from the Hokuriku Shinkansen railway as stimuli. The results indicated the combined effect of noise and vibration on disturbances in thinking and reading task at low levels of noise exposure. Maigrot et al. [12] also conducted an experimental study to investigate interaction effects of noise and vibration on annoyance. They found that no influence of vibration level on noise annoyance was detected and a weak influence of noise level on vibration annoyance in a high vibration level.

This study aims at clarifying the mutual effect of noise and vibration on annoyance and establish %HA due to railway noise or vibration, produced by high-speed railway and conventional railway, as a function of noise and ground-borne vibration exposures. The authors already clarified %HA due to railway noise as a function of noise and ground-borne vibration exposures, taking the railway category (the Shinkansen railway and conventional railway) into account [13]. In this paper, to formulate the relationship between each of noise and ground-borne vibration exposures from railway and %HA due to vibration, we compiled the datasets through 13 socio-acoustic surveys conducted separately over the past 25 years in Japan. Applying a logistic regression analysis to the datasets, we discuss each effect of the railway category and the noise exposure on vibration annoyance associated with railway.

Socio-acoustic surveys

Individual datasets for conventional railways (CR) analyzed in this paper were derived from six surveys CR01 to CR06 shown in Table 1. On the other hand, individual datasets for the Shinkansen railways (SR) were derived from seven surveys SR01 to SR07 shown in Table 2. The surveys were conducted separately, except for CR06 and SR05 surveys conducted along the Kyushu Shinkansen line. All the datasets were equipped with noise exposure, ground-borne vibration exposure (measurements in vertical direction) and annoyance due to railway vibration (5-point verbal scale).

CR02, CR06, SR02, SR04 and SR05 targeted inhabitants living not only in detached houses (DH) but also in apartment houses (AH). For example, noise levels from railways are much lower in AH made of reinforced concrete than those in wooden DH, because of a marked difference in soundproof performance. Similarly, the foundation of DH is greatly different from that of AH. Whereas vertical railway-induced ground-borne vibration slightly increased when transmitted to DH and that decreased when transmitted to AH. Taking these into consideration, in this paper, only data for detached houses were analyzed.

Table 1: Outline of conventional railway survey datasets

Survey	FY	Location	Method [a]	Annoyance Scale	Sample size
CR01	‘97	Kanagawa	Visit-Mail	unbearable	310
CR02	‘02	Fukuoka	Visit-Mail	ICBEN	422
CR03	’04 − ‘06	Kanagawa	Visit-Mail	ICBEN	653
CR04	‘11	Saitama	Visit-Mail	ICBEN	171
CR05	’08 – ‘09	Kumamoto	Visit-Visit	ICBEN	621
CR06	’11 – ‘12	Kumamoto	Visit-Visit	ICBEN	1055

a: Distribution-collection method.

Table 2: Outline of Shinkansen railway survey datasets

Survey	FY	Location	Line [a]	Method [b]	Annoyance Scale	Sample size
SR01	’95 – ‘96	Kanagawa	TSL	Visit-Mail	unbearable	870
SR02	’01 – ‘03	Kanagawa	TSL	Visit-Mail	ICBEN	872
SR03	‘03	Fukuoka	SSL	Visit-Mail	ICBEN	358
SR04	‘04	Aichi	TSL	Interview	ICBEN	175
SR05	’11 – ‘12	Kumamoto	KSL	Visit-Visit	ICBEN	1055
SR06	’13	Kumamoto	HSL	Mail-Mail	ICBEN	294
SR07	‘16	Ishikawa & Toyama	HSL	Mail-Mail	ICBEN	927

a: Tokaido Shinkansen line (TSL), Sanyo Shinkansen line (SSL), Hokuriku Shinkansen line (HSL), and Kyushu Shinkansen line (KSL).
b: Distribution-collection method.

Noise and ground-borne vibration exposures

Measurement of noise and ground-borne vibration from railway was conducted on a site-by-site basis for each survey. For the included surveys except SR04, measurement was performed after the social survey was completed. Conversely, SR04 survey estimated the exposures utilizing noise and ground-bore vibration measurement that Nagoya city government carried out before the social survey. It should be noted that vibration exposure was not estimated for some inhabitants in the SR03 survey.

Regarding noise measurement, A-weighted sound exposure level (L_{AE}) of the pass-by noise was measured or estimated at several points with different distances from the rail track. At each point, day-evening-night sound pressure level (L_{den}) as noise exposures was calculated as the mean energy value of the L_{AE} value and the frequency of service during the day (7:00–19:00), evening (19:00–20:00) and night (22:00–7:00). For the datasets providing $L_{\mathrm{Aeq,24h}}$ or L_{dn} value as noise exposure, we transformed the value into L_{den} value based on the ratio of the frequency of service in each time category. From the above results, depending on noise emission and propagation conditions, one or more distance attenuation equations were formulated for each noise index via logarithmic regression. Then, the noise exposure to each respondent was estimated based on the corresponding formula.

Similarly, the maximum value of Vibration Level (JIS C 1510) [14] in the vertical direction (L_{Vzmax}) of the pass-by ground-borne vibrations at almost the same points as the noise measurement. The reference acceleration of the vibration level is 10^{-5} m/s^2. The maximum-based index (L_{Vmax}) was calculated from the mean value of the top 50% of the measured L_{Vzmax} values. The vibration exposure for each respondent was estimated using the same method as that for noise exposure. In this study, we present the following relationship of L_{Vzmax} and maximum transient vibration value (MTVV: m/s^2) [15] for vertical ground-borne vibrations caused by the Shinkansen railways [16]: $10\log_{10}(MTVV/10^{-5})^2 = L_{Vzmax} + 1.8$.

The noise and vibration exposure values were rounded to one decimal place in this paper.

RESULTS

Demographic factors

Table 3 shows the relative frequency distribution of demographic factors. Overall, there were more female respondents than male respondents. Respondents aged 50 years or older accounted for more than 70% of each railway. This may have been driven by the fact that the analysis examined only detached houses. Although we did not calculate the proportion of housing structure, wooden house probably accounts for about 90%.

Table 3: Demographic factors

Item	Category	CR	SR
Sex	Male	845(41%)	1612(44%)
	Female	1211(59%)	2024(56%)
Age	Less than 30	91(4%)	151(4%)
	30-39	148(7%)	417(11%)
	40-49	283(14%)	444(12%)
	50-59	471(23%)	855(23%)
	60-69	564(27%)	1018(28%)
	70 or over	524(25%)	780(21%)

Subsequently, L_{den} and L_{Vmax} values were compared among the railways. Table 4 shows the results of cross tabulating the categories of L_{den} (≥ 35 dB) and L_{Vmax} (≥ 35 dB) for each railway. The categories of exposures were divided into 10-dB intervals. The parentheses in the table indicate the relative frequency of L_{den} and L_{Vmax} categories.

There was no significant difference in the relative distribution of L_{Vmax} category between CR and SR. On the other hand, it can be seen that L_{den} categories for CR were distributed at relatively higher range than those for SR.

Table 4: Cross table between noise and vibration exposures

L_{den} / L_{Vmax}	CR					SR			
	35-44	45-54	55-64	65-	Total	35-44	45-54	55-	Total
35-44	146	246	115	4	511 (24%)	235	651	23	909 (25%)
45-54	128	350	392	159	1029 (49%)	234	1304	141	1679 (45%)
55-64	0	19	229	248	496 (24%)	116	528	265	909 (25%)
65-74	0	0	2	53	55 (3%)	0	39	171	210 (6%)
Total	274 (13%)	615 (29%)	738 (35%)	464 (22%)	2091	585 (16%)	2522 (68%)	600 (16%)	3707

Logistic regression analysis

To quantitatively evaluate the effects of exposures and the difference in the railway category on vibration annoyance from the railway, we applied a multiple logistic regression analysis to the datasets using IBM SPSS Statistics 27.

In this paper, highly annoyed people by railway noise were defined as respondents using about 72% of the 5-point annoyance scale (i.e., the upper 28%). In particular, the highly annoyed people were defined as the respondents answering the highest category (Category 5) and 40% of the respondents answering the second highest category (Category 4) in the annoyance scale. The highly annoyed people of the Category 4 were randomly sampled from the respondents [17].

The analysis was applied to highly annoyed people as the dependent variable, while exposures (L_{Vmax} and L_{den}), Railway category, Sex, Age, and the interaction variables (Railway category * L_{Vmax}, Railway category * L_{den}, L_{Vmax} * L_{den}) were included as independent variables. Taking the estimation accuracy of low-level exposures into account, we excluded data with L_{den} and L_{Vmax} of less than 35 dB and used data with L_{den} and L_{Vmax} of 35 dB or more for the analysis.

As a result of the first analysis, the interaction variable of Railway category * L_{den}, which was not significant, was excluded. Tables 5 shows the odds ratio (OR) and the lower/upper limit of the 95% confidence interval (LCI/UCI) of each category. The OR was based on the following reference categories: CR in Railway type, Male in Sex and 40-59 in Age.

As shown in Table 5, the OR and LCI of SR in the railway category were more than 1. More inhabitants are potentially highly annoyed by ground-borne vibrations along the Shinkansen railway than along the conventional railway. Female in Sex shows the OR and UCI with less than 1. Therefore, male is more annoyed by railway noise than female. Age had no significant impact on railway noise annoyance.

As the ORs and LCIs of L_{Vmax} and L_{den} were more than 1, noise and vibration exposure had significant effect on vibration annoyance. Thus, the %HA increased with an increase not only in vibration exposure but also in noise exposure. Comparing the ORs among exposures, L_{Vmax}

was slightly larger than L_{den}. For the interaction items, Railway category * L_{Vmax} and L_{Vmax} * L_{den}, the OR and UCI are less than 1. This means the effect of vibration exposure on vibration annoyance differs by the railway category or noise exposure.

Table 5: Multiple logistic regression analysis of HA due to railway vibration

Item	Category	*B*	*SE*	*p*	OR	LCI	UCI
Railway Category	CR	1					
	SR	1.047	0.144	0.000	2.848	2.149	3.774
Sex	Male	1					
	Female	-0.308	0.087	0.000	0.735	0.62	0.871
Age	Less than 40	-0.198	0.139	0.153	0.82	0.625	1.077
	40-59	1					
	60 or over	0.007	0.092	0.94	1.007	0.841	1.205
L_{Vmax}		0.103	0.010	0.000	1.109	1.088	1.13
L_{den}		0.091	0.010	0.000	1.095	1.075	1.116
Railway Category*L_{Vmax}		-0.071	0.017	0.000	0.931	0.902	0.962
L_{Vmax}* L_{den}		-0.005	0.001	0.000	0.995	0.994	0.997
Constant		-12.248	0.714	0.000	0.000		

Discussion

Based on a reanalysis of the datasets compiled in six and seven socio-acoustic surveys conducted separately in Japan, we examined each effect of noise and ground-bore vibration on vibration annoyance along the Shinkansen or conventional railway lines.

In this study, it was confirmed that noise exposure affects vibration annoyance, similar to the findings obtained in previous studies. When simply comparing the ORs of both exposures, the OR of vibration exposure on vibration annoyance is slightly larger than that of noise exposure. According to rough calculation, without considering the interaction, the OR per 10 dB change in L_{Vmax} almost equals that per 11 dB (≈ 0.103/0.091) change in L_{den}. According to the previous study addressing annoyance due to railway noise [13], the OR per 5 dB change in L_{den} is almost equivalent to that per 13 dB change in L_{Vmax}. Even if considering the interactive effects on vibration annoyance, it seems that the effect of noise exposure on vibration annoyance is relatively larger than that of vibration exposure on noise annoyance.

Regarding the railway category, ground-borne vibrations from the Shinkansen railway are more annoying than those from conventional railway. This may suggest that negative attitudes towards the Shinkansen railway increase not only noise annoyance but also vibration annoyance. On the other hand, the OR of the interaction between the railway category and L_{Vmax} was less than 1. This can be interpretated that the effect of vibration exposure on vibration annoyance for the Shinkansen railway is smaller than that for conventional railway. However, the effect of the railway category certainly cancels the interaction effect; the difference in %HA due to vibration is not significant between the Shinkansen railway and conventional railway.

Conclusion

To quantitatively evaluate each effect of the railway category and noise exposure on vibration annoyance of people living along railway lines, we performed a secondary analysis of previous socio-acoustic surveys conducted in Japan. Individual datasets, exposures and annoyance associated with noise and vibration from a railway, derived from the previous thirteen surveys were used for analysis. Applying a multiple logistic regression analysis to the datasets, we confirmed the railway category had significant and large effect on vibration annoyance. We also clarified the effect of noise exposure on vibration annoyance not only for high-speed railway but also for conventional railway. In addition, we expressed the effect of the railway category on vibration annoyance in L_{Vmax}. In the future, we will proceed with research focusing on the modeling of the mutual effect of noise and vibration on annoyance.

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