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Combined effect of vibrations on railway noise annoyance

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ABSTRACT

In Japan, annoyance due to noise from the high-speed "Shinkansen" railways is more annoying than that from conventional railways, as reported in the previous study. The reasons for the difference have been explored mainly from psychological point of view. A previous comparison survey along the Shinkansen and conventional railways found that inhabitants living along the Shinkansen railways had negative attitudes to the noise. Therefore, no recognition of necessity of noise from the Shinkansen railways was considered to bring about higher annoyance than that from conventional railways. In addition, the combined effect of noise and ground-borne vibrations from the Shinkansen railways on annoyance could increase higher annoyance. However, each effect of ground borne vibrations as well as negative attitudes on noise annoyance has not been quantitatively evaluated. We performed a secondary analysis using individual datasets, exposures and annoyance associated with noise and ground-borne vibrations from the railways, derived from the previous twelve surveys. Applying a multiple logistic regression analysis to the datasets, we quantitatively provided the effects of negative attitudes and ground-borne vibrations on noise annoyance.

Keywords: Annoyance, Noise, Ground-borne vibrations, Logistic regression analysis, Combined effect

1. INTRODUCTION

In European countries and the United States, studies on adverse effects of noise on people have been energetically addressed. For example, Miedema et al. (1) conducted a meta-analysis using the socio-acoustic survey data archive of TNO (The Netherlands Organization for Applied Scientific Research). They derived individual exposure-response relationship for aircraft, road traffic and railway noises, and revealed lower annoyance due to railway noise than that of noise from other transportations. Since similar results had been reported in other studies conducted in Europe, "Railway bonus" of around 5 dB, are reflected in the environmental standards of European countries.

On the other hand, results from socio-acoustic surveys in Japan have not supported the existence of "Railway bonus". Yokoshima et al. (2) and Ota et al. (3) conducted a secondary analysis using the Socio-Acoustic Survey Data Archive (SASDA), and have established relationships between exposure and prevalence of noise annoyance for each mode of transportation. The prevalence of annoyance due to military aircraft noise is the highest, followed by the Shinkansen railway, civilian aircraft, conventional railway, and road traffic noises. This finding indicates that there is no "Railway Bonus" in Japan, unlike European countries.

On the other hand, in "ENVIRONMENTAL NOISE GUIDELINES for the European Region" (4), published in October 2018, recommended exposure levels for environmental noise in order to protect population health. Since respective recommendation values of L_{den} for road traffic and railway noise are 53 dB and 54 dB, the difference between the two noise sources is not clear. In addition, the guidelines develop no recommendation for high-speed railway. Socio-acoustic surveys in Japan revealed higher annoyance due to noise from the Shinkansen railways than that from conventional railways. Therefore, it is difficult to sufficiently discuss community response to noise from high-speed trains based on the datasets for conventional railway noise. .

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Several studies were performed to clarify the reason for the difference in community response between conventional and high-speed railways. Comparing community response to general noise in residential areas along the Shinkansen and conventional railways, Tamura (5) found that noise from the Shinkansen railway is regarded more negatively than conventional railway noise. He also indicated that inhabitants living in the areas along the Shinkansen railway are generally concerned with noise issues and recognize no need for the Shinkansen railway. Subsequently, Yokoshima et al. (6, 7) clarified that combined effect of noise and ground-borne vibrations on annoyance from the Tokaido Shinkansen railway increases higher individual annoyance. Furthermore, Yokoshima et al. (8) performed a secondary analysis using individual datasets associated with noise and ground-borne vibrations from the Shinkansen railways. The datasets were based on six socio-acoustic surveys which were separately conducted in residential areas along the various Shinkansen lines. Applying a logistic regression analysis to the datasets, they confirmed the combined effects of noise and ground-borne vibrations from the Shinkansen railways on annoyance, and provided the representative relationship between the combination of noise and vibration exposures, and the prevalence of each annoyance.

The previous studies suggested the negative attitudes and combined effect of ground-borne vibrations increase higher annoyance from noise due to high-sped railways than that from conventional railways. However, each effect on noise annoyance has not been quantitatively evaluated. In particular, it is very important to develop the evaluation method for community response to combined environment factors. In this paper, we performed a secondary analysis using the datasets derived from previous surveys conducted in residential areas along the railways in Japan (7 and 5 datasets for Shinkansen and conventional railways, respectively). Applying a multiple logistic regression analysis to the datasets, we quantitatively provided the effects of ground-borne vibrations and negative attitudes on noise annoyance.

2. METHODS

2.1 Socio-acoustic surveys

Individual datasets for conventional railways (CR) analyzed in this paper were derived from five surveys CR01 to CR05 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 CR05 and SR05 surveys conducted along the Kyushu Shinkansen line. All the datasets were equipped with noise exposure, vibration exposure (measurements in vertical direction) and annoyance due to railway noise (5 point verbal scale).

CR02, CR05, SR02 and SR05 targeted inhabitants living not only in detached houses (DH) but also in apartment buildings (AB). For example, noise levels from railways are much lower in apartment buildings made of reinforced concrete than those in detached wooden houses, because of a marked difference soundproof performance. Similarly, foundations of detached houses are greatly different from those of AB. Vertical railway-induced ground-borne vibrations slightly increased when transmitted to DH and decreased when transmitted to AB. 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 [a]	Method	Housing type (DH; AB) [c]	Annoyance	Response proportion (%) [e]	Sample size
CR01	1997	KNG Pref.	Visit-Mail [b]	DH	unbearable	79	310
CR02	2002	KNG Pref.	Visit-Mail [b]	DH & AB	ICBEN [d]	64	422
CR03	2004−2006	FKO Pref.	Visit-Mail [b]	DH	ICBEN [d]	49	653
CR04	2011	STM City	Visit-Mail [b]	DH	ICBEN [d]	29	170
CR05	2011–2012	KMM Pref.	Visit-Visit [b]	DH & AB	ICBEN [d]	30	559

a: Kanagawa (KNG), Fukuoka (FKO), Saitama (STM), and Kumamoto (KMM).
b: Distribution-collection method.
c: Detached house (DH) and Apartment building (AB).
d: International Commission on Biological Effects of Noise (ICBEN).
e: Response proportion of detached houses.

Table 2 – Outline of Shinkansen railway survey datasets

Survey	FY	Location [a]	Line [b]	Method	Housing type (DH; AB) [d]	Annoyance	Response proportion (%) [f]	Sample size
SR01	'95–'96	KA Pref.	TSL	Visit-Mail [b]	DH	unbearable	72	709
SR02	'01–'03	KA Pref.	TSL	Visit-Mail [c]	DH & AB	ICBEN [e]	57	872
SR03	'03	FU Pref.	SSL	Visit-Mail [c]	DH	ICBEN [e]	66	358
SR04	'04	NG City	TSL	Interview	DH	ICBEN [e]	58	175
SR05	'11–'12	KU Pref.	KSL	Visit-Visit [c]	DH & AB	ICBEN [e]	45	559
SR06	'13	NA Pref.	HSL	Mail-Mail [c]	DH	ICBEN [e]	45	294
SR07	'16	IS & TO Prefs.	HSL	Mail-Mail [c]	DH	ICBEN [e]	52	927

a: Kanagawa (KA), Fukuoka (FU), Nagoya (NG), Kumamoto (KU), Nagano (NN), Ishikawa (IS) and Toyama (TO).
b: Tokaido Shinkansen line (TSL), Sanyo Shinkansen line (SSL), Hokuriku Shinkansen line (HSL), and Kyushu Shinkansen line (KSL).
c: Distribution-collection method.
d: Detached house (DH); Apartment building (AB).
e: International Commission on Biological Effects of Noise (ICBEN).
f: Response proportion of detached houses.

2.2 Measurement

Measurement of noise and ground-borne vibrations from railways 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, for the SR04 survey, the city government carried out its measurement 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 levels (L_{AE}) of the pass-by noise from the trains were measured at several points at different distances from the track. Some surveys estimated the L_{AE} values from the maximum A-weighted and S-weighted sound pressure level (L_{ASmax}). At each point, day-evening-night sound pressure level (L_{den}) as noise exposures was calculated as the mean energy value of measured L_{AE} and the number of pass-by trains during the day-time (7:00–19:00), evening-time (19:00–20:00) and night-time (22:00–7:00). 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 vibration level in the vertical direction (L_{Vzmax}) on the surface of the ground was measured 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 relationship of L_{Vzmax} and maximum transient vibration value ($MTVV$: m/s^2) (9) for vertical ground-borne vibrations caused by the Shinkansen railways. Shimoyama et al. (10) indicated the following approximate expression:

$$10\log_{10}(MTVV/10^{-5})^2 = L_{Vzmax} + 1.8$$

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

3. RESULTS

3.1 Demographic factors

Table 3 shows the relative frequency distributions of demographic and housing factors. Overall, there were proportionally 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. About 90% of the detached houses had wooden frame structures.

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} (38 dB ≤ L_{den} 67 dB B) and L_{Vmax} (35 dB ≤ L_{Vmax} ≤ 64 dB) for each railway. The ranges of Exposures were divided into 5-dB intervals. The parentheses in the table indicate the relative frequency of L_{den} and L_{Vmax} categories. L_{den} values for the CR were distributed in higher level ranges than those for the SR. On the other hand, comparing among the railways at the same L_{den} category, it can be seen that L_{Vmax} values for the SR were distributed at relatively higher ranges than those for the CR.

Table 3 – Demographic factors and housing structure

Item	Category	CR	SR
Sex	Male	834 (40%)	1670 (44%)
	Female	1256 (60%)	2151 (56%)
Age	Less than 30	72 (3%)	156 (4%)
	30-39	156 (7%)	286 (7%)
	40-49	303 (14%)	631 (16%)
	50-59	477 (23%)	899 (23%)
	60-69	566 (27%)	1060 (28%)
	70 or over	521 (25%)	810 (21%)
Housing structure	Wooden	1878 (90%)	3395 (88%)
	Others	220 (10%)	461 (12%)

Table 4 – Cross tabulate between noise and vibration exposures

L_{Vmax} / L_{den}	CR				SR			
	45-44	45-54	55-64	Total	45-44	45-54	55-64	Total
38-42	80	79	0	159 (9%)	68	101	55	224 (6%)
42-47	97	96	0	193 (11%)	366	501	164	1031 (31%)
48-52	90	204	5	299 (18%)	360	774	303	1437 (40%)
53-57	83	209	59	351 (21%)	106	279	270	655 (19%)
58-62	76	186	98	360 (21%)	5	24	111	140 (4%)
63-67	9	160	174	343 (20%)	0	3	4	7 (0%)
Total	435 (26%)	934 (55%)	336 (20%)	1705	905 (26%)	1682 (48%)	907 (26%)	3494

3.2 Logistic Regression

To quantitatively evaluate the effects of ground-borne vibrations and negative attitudes on noise annoyance from the railways, we applied a multiple logistic regression analysis to the datasets using IBM SPSS Statistics 23.

As indices of noise annoyance due to railway noise, the responses of the most annoyed category, and of either category of the most annoyed or next annoyed were defined as "Extremely Annoyed" (EA) and "Very Annoyed" (VA), respectively. The analysis was applied to EA/VA as the dependent variable, while exposures (L_{den} and L_{Vmax}), railway type (CR and SR), sex, age, and the interaction between railway type and L_{Vmax} category were included as independent variables. Taking the estimation accuracy of exposures into account, L_{den} (38–67 dB) and L_{Vmax} (35–64 dB) were divided into 5- or 10-dB intervals, respectively.

Tables 5 shows the odds ratio (OR) and the lower/upper limit of the 95% confidence interval (LCI/UCI) of each category for EA/VA due to railway noise. The OR was based on the following reference categories: CR (railway type), Male (sex), <30 (age), 38–42 dB (L_{den}), 45–54 dB (L_{Vnax}), and SR*45–54 dB (railway type*L_{Vmax}).

As shown in Table 5, the OR of SR (railway type) was larger than 1 and the LCI was also more than 1. Female (sex) showed the OR and UCI with less than 1. Therefore, female was less annoyed by railway noise than male. Age had no significant impact on railway noise annoyance.

Within an L_{den} range of 48–52 dB or above, the OR and LCI were larger than 1. Subsequently, within an L_{Vmax} range of 35–44 dB, the OR and UCI were smaller than 1; within an L_{Vmax} range of 55–64 dB, the OR and LCI were larger than 1. These results show a significant increase effect in noise annoyance in the L_{den} range of 48–52 dB or above and a significant increase effect of L_{Vmax} on noise annoyance. For the interaction item, the UCI of SR*35–44dB and LCI of SR*55–64dB were larger and smaller than 1, respectively. Therefore, there was no interaction between railway type and vibration exposure for noise annoyance. This result suggests no difference in the average slope of the relationship between L_{Vmax} and the prevalence of noise annoyance by railway type.

Table 5 – Logistic regression analysis of EA/VA due to railway noise

Item	Category	EA			VA		
		OR	95% CI		OR	95% CI	
Railway type	CR	1			1		
	SR	2.415	1.740	3.351	2.860	2.255	3.628
Sex	Male	1			1		
	Female	0.714	0.584	0.874	0.778	0.671	0.901
Age	<30	1			1		
	30-39	0.655	0.352	1.220	0.633	0.406	0.988
	40-49	0.900	0.521	1.554	0.726	0.488	1.08
	50-29	1.058	0.628	1.784	0.933	0.639	1.362
	60-69	1.109	0.660	1.864	0.984	0.676	1.432
	70≤	0.651	0.377	1.123	0.628	0.426	0.927
L_{den}	38–42 dB	1			1		
	43–47 dB	1.461	0.705	3.031	1.820	1.112	2.981
	48–52 dB	4.102	2.067	8.141	4.787	2.989	7.669
	53–57 dB	3.530	1.750	7.121	4.500	2.775	7.299
	58–62 dB	9.663	4.677	19.967	9.117	5.429	15.311
	63–67 dB	11.746	5.281	26.126	15.079	8.538	26.628
L_{Vmax}	35–44 dB	0.621	0.439	0.879	0.696	0.547	0.886
	45–54 dB	1			1		
	55–64 dB	1.552	1.197	2.012	1.421	1.166	1.731
Railway type* L_{Vmax}	SR*35–44dB	0.582	0.292	1.161	0.821	0.511	1.333
	SR*45–54 dB	1			1		
	SR*55–64 dB	1.064	0.641	1.764	0.819	0.557	1.203
Constant			0.076			0.206	
Area Under the Curve (AUC)			0.72			0.70	

4. DISCUSSION

Based on a reanalysis of datasets compiled in five and seven socio-acoustic surveys conducted separately in Japan, we examined each effect of ground-borne vibrations and negative attitudes on noise annoyance of inhabitants living along the Shinkansen or conventional railway lines.

In this study, we confirmed the combined effect of ground-borne vibrations on noise annoyance. According to rough calculation, the OR of 10 dB increase in vibration exposure was estimated to be about 1.5 on geometric average. On the other hand, re-calculating the ORs of 5 dB increase in noise exposure, based on the neighboring category, became 0.86–2.81 (EA) and 0.94–2.63 (VA); geometric average of the ORs obtained was about 1.7. These results provide that the OR of change of 5 dB in noise exposure is equivalent to that of 13 dB (≈ 10*log1.7/log1.5) in vibration exposure.

Regarding railway type, noise from the Shinkansen railways is more annoying than that from conventional railways. As Tamura pointed out in the previous report, negative attitudes towards the Shinkansen railways increase its noise annoyance (5). Whereas the OR of railway tape was about 2.4, the averaged OR of 5 dB increase in noise exposure for EA was determined to be about 1.6. When the OR of railway type is expressed in noise exposure L_{den}, negative attitudes towards the Shinkansen railway noise equal the increase of about 9 dB (≈ 5*log2.4/log1.6). Similar calculation for VA provided equivalent increase of about 10 dB in noise exposure. Thus, very annoyed response is more likely to be affected by negative attitudes than extremely annoyed response.

5. CONCLUSIONS

To quantitatively evaluate each effect of negative attitudes and ground-borne vibrations increasing higher noise annoyance of people along railway lines, we performed a secondary analysis. Individual datasets, exposures and annoyance associated with noise and ground-borne vibrations from the railways, derived from the previous twelve surveys were used for analysis. Applying a multiple logistic regression analysis to the datasets, we confirmed negative attitudes had significant effect on noise annoyance at the 5 % level. We also clarified the combined effect of ground-borne vibrations on noise annoyance not only for high-speed railways but also for conventional railways. In addition, we expressed the effect of negative attitudes on noise annoyance in L_{den}. In future research, we intend to address the combined effects of noise exposure on vibration annoyance from railways. Further, we advance research to develop evaluation methods for combination of noise and ground-borne vibrations.

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