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A study on the influence of noise and vibration on the living environment along the Hokuriku Shinkansen railway

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ABSTRACT

One year after opening of the Hokuriku Shinkansen (high-speed) railway, we conducted a social survey targeting detached houses along that rail in 2016. Noise and vibration exposure level were estimated at outdoor points closest to the noise source side of the house. Of the 1,980 people contacted, there were 1,022 valid respondents. The purpose of this research is to investigate the relationship between noise and vibration exposure and social responses. Regarding the noise annoyance and some living activity disturbances, it was shown that the responses of residents living in areas without the conventional railway are higher than those in areas running parallel to conventional railway. This tendency was remarkable especially in areas with high vibration exposure caused by Shinkansen railway. High vibration annoyance was shown in areas without the conventional railway, while there was no difference by the degree of the noise exposure.

Keywords: Social survey, Shinkansen, High-speed railway, Annoyance, Exposure-response relationship

1. INTRODUCTION

The Hokuriku Shinkansen (high-speed) railway connects Nagano Station to Kanazawa Station in Ishikawa Prefecture, and has been operating since March 2015 (Fig. 1). This route is one of the new Shinkansen lines, and routes of Hokkaido, Tohoku, and Kyushu routes are expected to be gradually operational (1). In this way, the Shinkansen railway has begun to operate across Japan, and the impact of its noise and vibration on the living environment of residents along the rail is an important issue.

The environmental quality standard for Shinkansen super express railway noise was notified in 1975, and a standard value (peak noise level) was established for each area category type. As more than 40 years have passed since the environmental standards were notified, and equivalent noise levels have been applied as the standard value of environmental standards for general noise, it is necessary to reconsider the appropriate evaluation value for Shinkansen railway noise in Japan.

The authors conducted a social survey of detached houses located along Toyama and Ishikawa Prefectures in November 2016, one year after the Hokuriku Shinkansen railway became operational in March 2015 [1]. In May of the following year, a survey was conducted to estimate the noise and vibration exposures in the areas along the Shinkansen railway. The Shinkansen railway operates 92 trips a day, and it does not operate from 24:00 to 6:00 due to restrictions.

The purpose of this study is to investigate the relationships between noise and vibration exposure and community responses.

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Figure 1 – A Hokuriku Shinkansen railway

2. ANALIZING THE DATA

2.1 Social Survey

The data analyzed in this study were obtained from a social survey conducted in November 2016 in Ishikawa and Toyama Prefectures of detached houses along the Hokuriku Shinkansen railway (2). In survey areas in Ishikawa Prefecture, conventional railways run parallel to the Shinkansen railway except for some areas, while in most of the survey areas in Toyama Prefecture, the two railways do not run parallel (Fig. 2).

The target houses were all detached houses within 150 m of the Hokuriku Shinkansen railway. If there were no houses within 150 m, we targeted the first row of houses up to 210 m away from the railway line. In this survey, we decided to randomly select one respondent from each household by asking for the person whose birthday was closest to the designated date set. In addition, the subject of the questionnaire survey was living environment, and it was not presented as a survey on noise and vibration in particular. The survey included 43 question items on housing, regional environment, transportation, lifestyle, and personal factors. The questions on noise and vibration were prepared both as per 5-point verbal scale and 0 to 10-point numeric scale, following the guidelines and recommendations of the ICBEN Team 6 (3).

A total of 1,022 people responded to the questionnaire, and response rate was 51.6%. The respondents were predominantly male (56%), the same value as in the previous survey (4), and 90% of the respondents were over 40 years old (Table 1). This result reflects the dominant demographic of people living in detached houses in regional towns and cities in Japan. We used the WNS-6B scale (5) in the survey to judge sensitivity to noise. A cut-off point of 4/5 on the WNS-6B scale was used.

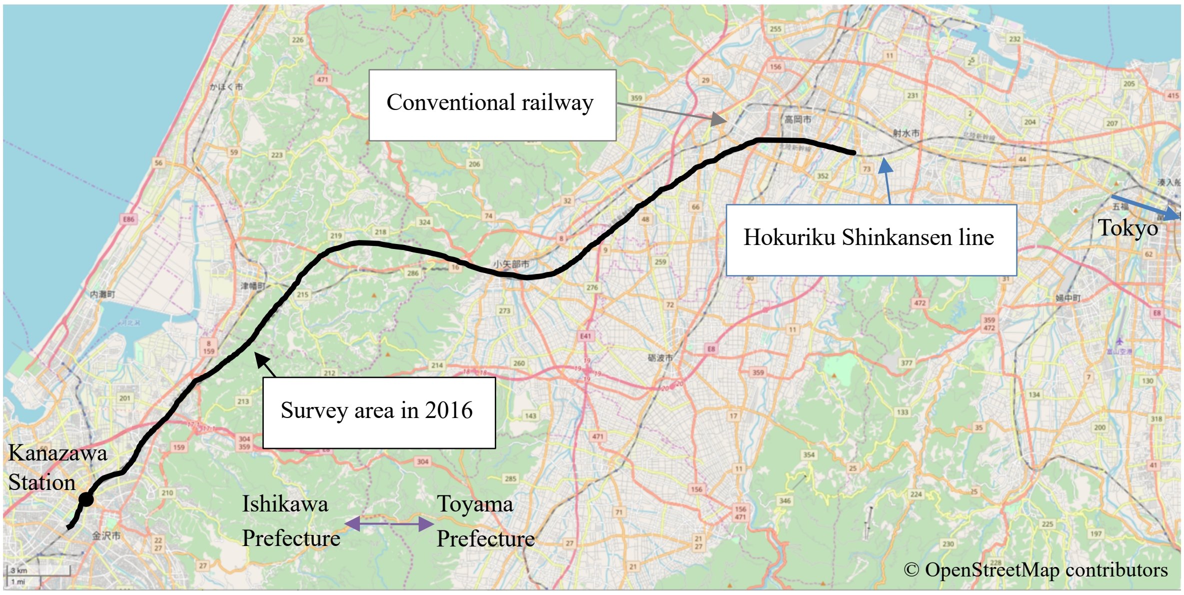


Figure 2 – Rout of Hokuriku Shinkansen and Area of Social Survey

Table 1 – Demographic attribute

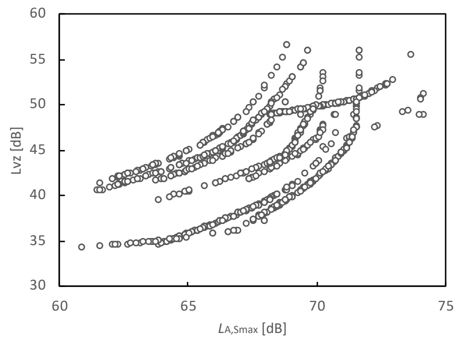
	Gender (n (%))			Family		Sensitivity	
Age	Male	Female	Total	size	(n (%))	WNS-6B	(n (%))
10s	4 (0.4)	6 (0.6)	10 (1.0)	one	116 (11.5)	0	42 (4.2)
20s	14 (1.4)	12 (1.2)	26 (2.6)	two	341 (33.8)	1	44(4.4)
30s	21 (2.1)	19 (1.9)	40 (3.9)	three	240 (23.8)	2	116(11.6)
40s	60 (5.9)	64 (6.3)	124 (12.2)	four	180 (17.8)	3	150(15.1)
50s	100 (9.9)	91 (9.0)	191 (18.8)	five	75 (7.4)	4	209(21.0)
60s	185 (18.2)	157 (15.5)	342 (33.7)	six	36 (3.6)	5	242(24.3)
70s or more	187 (18.4)	94 (9.3)	281 (27.7)	seven	16 (1.6)	6	193(19.4)
				eight	5 (0.5)		
				nine	1 (0.1)		
Total	571 (56.3)	443 (43.7)	1014 (100)	Total	1,010 (100)	Total	996 (100)

2.2 Estimation of Noise and Vibration Exposure

The Hokuriku Shinkansen railway has the maximum speed of 260 km/h, and the survey area has an elevated railway structure.

Noise and vibration measurements were conducted to estimate the noise and vibration exposures for the target houses. The noise exposure levels for the target houses were estimated by the prediction method of Nagakura et al. (6), and the predicted values were adjusted according to the values measured at 25 m. Vibration Levels, defined in a Japanese industrial standard with a reference acceleration of 10^{-5} m/s^2, were estimated by the distance attenuation prediction equations obtained from the measured value. The surveys were conducted in May 2017 at representative locations of each area, which were then classified into the eleven areas along the route in Ishikawa and Toyama Prefectures in consideration of the height of the structure and train speed. In each area, measurement points were provided in the range of 12.5 m to 100 m with reference to the close orbit center, and sound level meters (RION NL-31, 32, 42 and 62) and vibration level meters (RION VM-53 and NM-55) were used at each measurement point. Both exposure levels are outdoor levels of the target housing closest to the rail track.

Figure 3 shows the relation between noise and Vibration Levels. The X-axis is the mean of the maximum noise level measured in Slow dynamic characteristic (left), the day-evening-night equivalent sound level, and the Y-axis is the ground Vibration Level of the vertical direction. The range of Vibration Level was 30 to 60 dB, and the range of noise level was 60 to 75 dB $L_{\mathrm{A,Smax}}$ and 44 to 55dB L_{den} in the survey area. There were 114 houses with Vibration Levels above 50 dB and 209 houses with noise levels above 70 dB. Table 2 shows the number of the samples sorted in the estimated noise levels and the existence of conventional railway in the residential area. The Hokuriku Shinkansen railway is presently operating from Tokyo to Kanazawa Station. Therefore, the area to the west of Kanazawa Station runs only conventional railways, and the number of respondents in the area is 95.



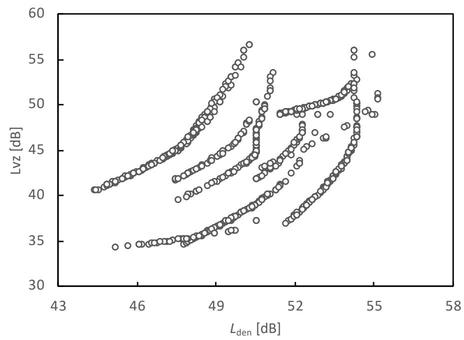


Table 2 – Sample sizes divided by noise level

$L_{A,Smax}$ [dB]	CR with	CR without	Total	L_{den} [dB]	CR with	CR without	Total	L_{night} [dB]	CR with	CR without	Total
west	95	-	95	west	95	-	95	west	95	-	95
60-63	8	31	39	44-48	47	127	174	33-36	116	17	133
63-67	137	127	264	48-51	191	177	368	36-38	341	66	407
67-71	351	161	512	51-54	289	21	310	38-41	138	249	387
71-74	99	13	112	50 <	68	7	75				
Total	690	332	1,022	Total	690	332	1,022	Total	690	332	1,022

CR: conventional railway, west: west area of Kanazawa Station

Figure 3 – Relationship between noise levels and Vibration Levels

3. ANALYSIS

3.1 Relationships between community response and exposure

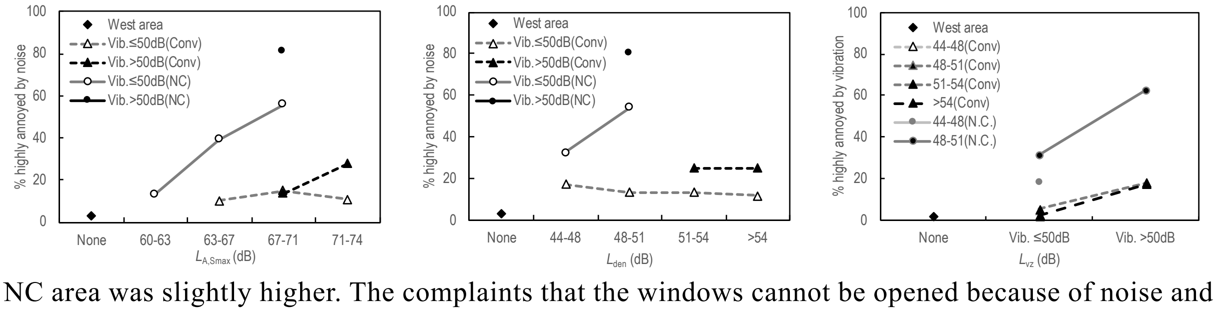
Figures 4 and 5 show the relationships between community responses and noise or vibration exposure levels. This paper defined the ratio of respondents who chose either of the top two categories in the 5-point verbal scale: % highly annoyed (7) and % highly disturbed.

Noise annoyance in the vicinity of a conventional railway (Conv) area evoked almost a constant response to the increase of $L_{A,Smax}$ and L_{den}, and the noise annoyance was high in the area where the Vibration Level was high. Further, the response of the area where the conventional railway does not run parallel (NC) to the Shinkansen railway in the range of 63-71 dB is much higher than that of Conv area. Thus, the result that the noise annoyance was greater in the area where the ground Vibration Level was high is similar to the results for Gidlöf-Gunnarsson et al. (8) and Yokoshima et al. (9). The result also shows that vibration annoyance was greater in the high noise level residential areas. In particular, the response in the range of 67-71 dB $L_{A,Smax}$ was high, and the vibration annoyance also tended to increase as the Vibration Level increased. Table 3 shows the multiple regression analysis of noise annoyance. This analysis was used by IBM SPSS Statistics 25. These models were included age, gender, family size and noise sensitivity (WNS-6B) as adjusted valuables. Both $L_{A,Smax}$ and L_{den} ware significant. Odds ratio of noise annoyance in the area with a conventional railway was significantly higher than that of without conventional railway. The vibration factor divided at 50 dB of Vibration Level was not significant.

Figure 5 shows the results of activity disturbances. Conversation and reading disturbances were low within this noise level range. For the TV/radio listening disturbance, the response in NC area and high Vibration Level areas was slightly high, and 38% were highly disturbed in the range of 48-51 dB L_{den}. The thinking disturbance was low in Conv area, and did not depend on L_{den}, but the response in

Figure 4 – Exposure-response relationships due to noise or vibration annoyance

(Conv: with a conventional railway, NC: without conventional railways)



NC area was slightly higher. The complaints that the windows cannot be opened because of noise and the rattling in NC area were higher than that in Conv area. In particular, the response rates of rattling

Table 3 – Results of multiple regression analysis for noise annoyance

			95% CI					95% CI		
		OR	lower	upper	p value		OR	lower	upper	p value
Noise exposure	$L_{A,Smax}$	1.205	1.112	1.305	<0.0001	L_{den}	1.542	1.059	1.259	0.001
Conventional	without	1				without	1			
railway	with	6.970	4.689	10.361	<0.0001	with	7.558	4.840	11.804	<0.0001
L_{vz}	≤50dB	1				≤50dB	1			
	>50dB	0.986	0.504	1.929	0.986	>50dB	1.298	0.676	2.489	0.433
CR* L_{vz}		0.970	0.898	7.747	2.637		2.573	0.878	7.544	0.085
Constant		5.6E-07					1.1E-04			

OR: Odds ratio, 95% CI: 95 % Confidence interval, CR: Conventional railway
Adjusted variables: Age, Gender, Family size, Noise sensitivity (5), L_{vz} (1: >50dB)

in the range of 48-51 dB L_{den} in NC area and large vibrations in residential areas were considerably high. Falling asleep disturbance in NC area was rather high in the range of 36-41 dB L_{night}; and in addition, the response to Vibration Level of over 50 dB more was even higher. As for being awakened in the same noise level section, the response tended to be smaller than the falling asleep disturbance. The fact that the service does not operate between 24:00 and 6:00 may influence being awakened a little. Further research is necessary because the sound generated by the rattling due to vibration may affect the listening disturbance.

3.2 Evaluation of Quietness, Satisfaction, and Preference for a residential area

This section presents the results of multiple logistic regression analysis for Quietness around the house, Satisfaction with the house and Preference for a residential area. These factors were evaluated on a 5-point verbal scale and were divided into two categories (1: 4 and 5, 0: 1-3) for the analysis. Table 4 shows the results of the analysis. Age, gender, family size, noise sensitivity, L_{den} and ground Vibration Level were included as explanatory variables. Noise and Vibration Levels were changed to the nominal scale. All these models were confirmed to be statistically significant by the Hosmer-Lemeshow test.

This analysis was based on the evaluation of under 50 dB L_{den} in the area with a conventional railway area (existence area). The evaluation of quietness in areas without conventional railway area (none area) was significant at >50 dB L_{den} (OR = 2.524, 95% CI: 1.334, 4.777). The factor of L_{vz} (1: >50dB) included in this model were also significant, and sound generated by vibration such as rattling may have affected quietness. The satisfaction of respondents living in none area were significant for both ≤50dB L_{den} (OR = 2.610, 95% CI: 1.195, 5.701) and >50 dB L_{den} (OR = 3.198, 95% CI: 1.318, 7.759). On the other hand, the evaluation of preference for a residential area did not show a significant different between a conventional railway area and a none area.

4. CONCLUSIONS

In this study, using the social survey data obtained one year after the Hokuriku Shinkansen railway started operating, we presented the exposure-response relationships including a viewpoint regarding the existence of conventional railway in residential area and the ground vibration level.

With regard to noise annoyance, it was shown that a high percentage of highly annoyed respondents live in high Vibration Level areas and areas that do not have conventional railways. Although not to the same degree as noise annoyance, similar trends were observed in activity disturbances. Regarding the quietness and satisfaction, it was also shown that the existence of conventional railway in residential areas impacts those evaluations. In other words, when the Shinkansen railway is opened in an area where there is no conventional railway, not only the noise annoyance, but also the evaluation of the quietness and satisfaction may be deteriorated in Japan.

In future research, it is necessary to investigate hierarchical causal models of noise annoyance and housing satisfaction, and to understand the extent to which noise and vibration affect community responses.

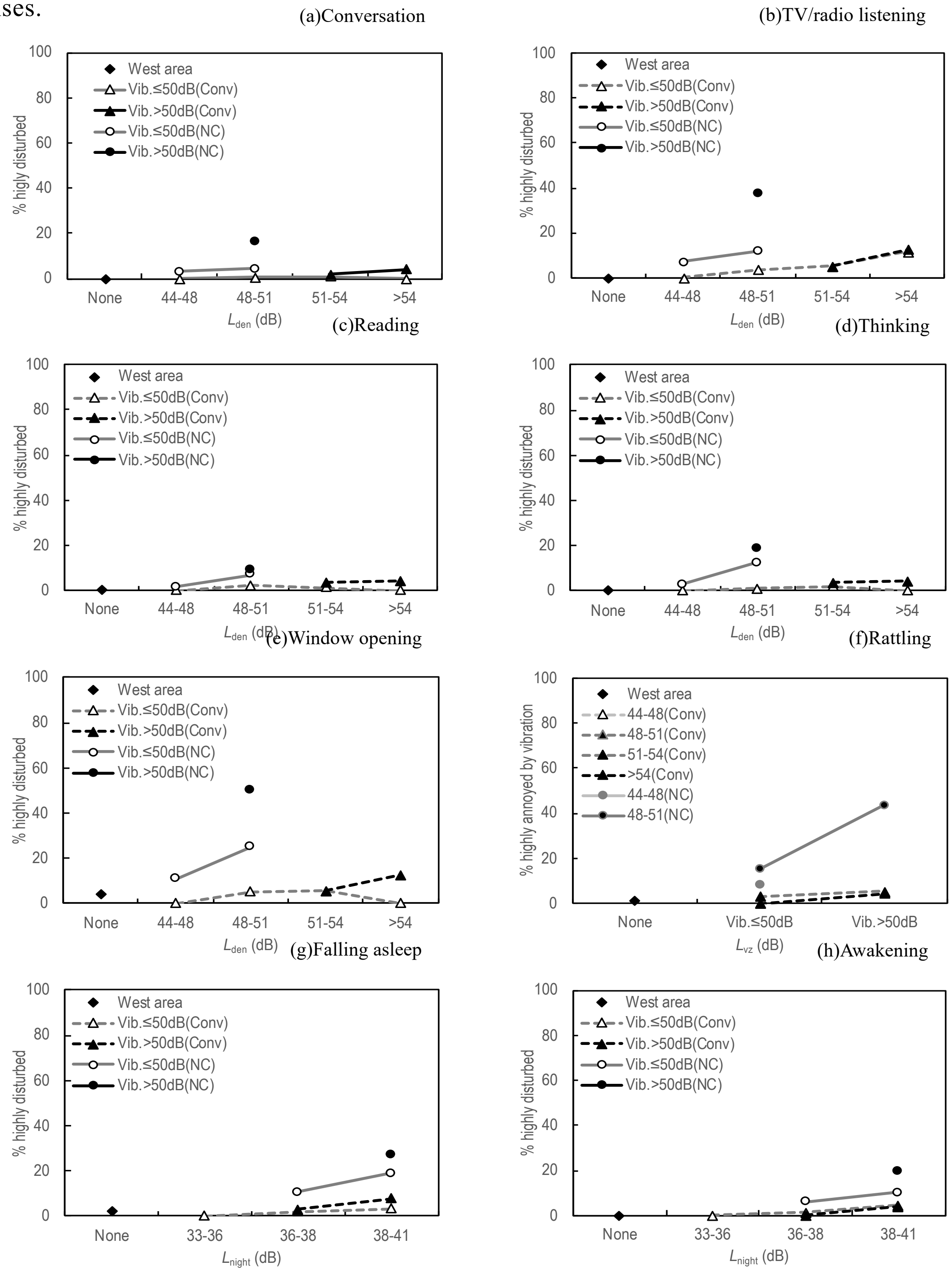


Figure 5 – Exposure-response relationships due to activity disturbances (Conv: with a conventional railway, NC: without conventional railways)

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Table 4 – Odds ratio and 95 % Confidence interval for the evaluation of house and residential area

		(a) Quietness				(b) Satisfaction			
			95% CI				95% CI		
		OR	lower	upper	*p* value	OR	lower	upper	*p* value
Conventional railway: exist									
L_{den}	≤50dB	1	-	-		1	-	-	
	>50dB	1.260	0.747	2.123	n.s.	1.707	0.797	3.656	n.s.
Conventional railway: none									
L_{den}	≤50dB	1.221	0.695	2.143	n.s.	2.610	1.195	5.701	0.016
	>50dB	2.524	1.334	4.777	0.004	3.198	1.318	7.759	0.010

		(c) Preference for a residential area			
Conventional railway: exist					
L_{den}	≤50dB	1	-	-	
	>50dB	1.377	0.369	5.135	n.s.
Conventional railway: none					
L_{den}	≤50dB	3.362	0.927	12.190	n.s.
	>50dB	2.485	0.533	11.578	n.s.

Quietness and Satisfaction; 1: bad or extremely bad, Preference for a residential area; 1: dislike or dislike very much

OR: Odds ratio, 95% CI: 95 % Confidence interval, n.s.: not significant

Adjusted variables: Age, Gender, Family size, Noise sensitivity (5), L_{vz} (1: >50dB)

2013.