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Effects of The Number of Noise Events from SHINKANSEN Railway on annoyance

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ABSTRACT

This paper describes the relationship between the number of Shinkansen noise events and annoyance. In Japan, the maximum noise level ($L_{A,Smax}$) has been adopted as the index for Environmental Quality Standards for Shinkansen Superexpress Railway Noise since 1975. As the number of trains has increased with the development of the Shinkansen railway network, it has been debated whether $L_{A,Smax}$ or some energy averaged index such as $L_{Aeq,24h}$ or L_{den} is more appropriate. The Ministry of Environment initiated nation-wide social surveys on Shinkansen noise in the areas along Shinkansen railways, that have 40 to 340 train pass-byes per day. We hypothesized that annoyance with Shinkansen railway noise increases as the number of noise events increases, even if maximum noise levels are equal. It was confirmed that an increased number of noise events increased the annoyance with Shinkansen railway noise up to approximately 200 per day, but the effect saturated after 300 per day. We conclude that the maximum noise level ($L_{A,Smax}$) and the number of Shinkansen noise events affect annoyance, but the number of Shinkansen noise events does not always cause in the listening and sleeping disturbances as much as annoyance, when we estimate the environmental quality for Shinkansen railway noise.

Keywords: Annoyance, Number of noise events, Railway noise

1. INTRODUCTION

In Japan, when the index for Environmental Quality Standards for Shinkansen Superexpress Railway Noise was established, the technical committee pointed out that as well as the maximum noise level, the number of noise events and duration of noise should also be considered. The technical committee concluded that it was only necessary to evaluate Shinkansen railway noise based on the maximum noise level for 100 to 250 Shinkansen train pass-byes per day, considering the technical difficulty in measuring and calculating energy averaged noise levels at the time. However, the current number of Shinkansen train pass-byes per day is 30 to 340.

This paper describes the relationship between the number of Shinkansen noise events and noise annoyance. In Japan, the maximum noise level ($L_{A,Smax}$) has been adopted as the index for Environmental Quality Standards for Shinkansen Superexpress Railway Noise since 1975. As the number of trains has increased with the development of the Shinkansen railway network, it has been debated whether $L_{A,Smax}$ or some energy averaged index, such as $L_{Aeq,24h}$ or L_{den}, is more appropriate for the index. The effects of the number of noise events on annoyance have been investigated in laboratory experiments and socials surveys. Rice [1] concluded that at >20 aircraft overflights per hour, the results agree reasonably well with the Noise and Number Index (NNI) concept, whereas at lower rates (4-8 overflights per hour) the peak level concept can be applied. Rylander et al. [2] identified that after approximately 70 overflights per 24 h, further increases do not cause further increases in annoyance.

In this study, we aim to investigate the effects of the number of Shinkansen noise events on annoyance and to draw the exposure-response curves for Shinkansen noise using the nation-wide social survey data on Shinkansen noise in Japan. Furthermore, we analyzed the relationship between the number of Shinkansen noise events and annoyance using multiple logistic regression models.

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2. METHODS

2.1 Social Surveys

The Ministry of Environment initiated nation-wide social surveys on Shinkansen railway noise in 2014 and 2017 in areas along the Shinkansen railway that have 40 to 340 trains pass-byes per day. Social surveys were conducted in 34 areas, as shown in Table 1 and Figure 1. There were 7, 8, 5, 10, 3, and 1 areas along the Tokaido, Sanyo, Kyushu, Tohoku, Jyoetsu, and Hokuriku Shinkansen lines, respectively. Although the Tokaido and Sanyo lines were operated before Environmental Quality Standards for Shinkansen Superexpress Railway Noise was established, the other lines were operated after the establishment. The number of Shinkansen train pass-byes in the survey areas is 40-340/day, as shown in Figure 2. When the number of pass-byes per day is divided into four categories (40-90/day, 90-190/day, 190-290/day, and 290-340/day), there are 10, 9, 5, and 10 areas in each category, respectively.

A face-to-face interview method was used. Forty questions were asked on house, residential environment, annoyance caused by environmental factors, activity interferences by Shinkansen railway noise, and sleep quality. Houses were selected in the area within approximately 150 m of a 1 km long strip of railway. The number of respondents (response rate, %) in the 2014 and 2017 surveys was 1,180 (31.0) and 293 (35.8), respectively.

Annoyance was evaluated verbally on a 5-point Likert scale (not at all, slightly, moderately, very, and extremely). Activity interferences (telephone/TV/radio listening, indoor conversation, sleeping, reading, and indoor resting) were evaluated with “yes” or “no,” and if the answer was “yes,” sleep disturbance was further evaluated on a 4-point frequency scale (not at all, occasionally, once or twice a week, and more than three times a week). % Very Annoyed (%VA) was defined as the rate of respondents who selected “extremely” or “very” at the sites. % Disturbed (%D) for daytime activities was defined as the rate of respondents who selected “yes” at the sites. %Very Sleep Disturbed (%VSD) for sleep disturbances was defined as the rate of respondents who selected “yes” and “more than three times a week” at the sites.

Table 1 – Social survey areas

Survey year	Shinkansen line	Area No.	Number of respondents	Response rate (%)
2014	Tokaido	1, 2, 3, 18, 19	211	27.4
	Sanyo	4, 5, 6, 7, 21, 22	252	28.9
	Kyusyu	8, 9, 23, 24	169	29.3
	Tohoku	10, 11, 12, 13, 14, 25, 26	347	34.7
	Jyoetysu	15, 16, 27	158	35.1
	Hokuriku	17	43	30.7
	All lines	-	1,180	31.0
2017	Tokaido	28, 29	98	32.7
	Sanyo	30, 31	98	32.7
	Kyusyu	32	51	34.0
	Tohoku	33, 34, 35	46	66.7
	All lines	-	293	35.8

2.2 Noise Measurement

Shinkansen railway noise levels were measured by the Ministry of Environment at reference points in 34 areas through social surveys in 2012, 2013, and 2017. The noise measurements were performed at No. 1-17 in 2012, No. 18-27 in 2013, and No. 28-35 in 2017. The reference points were positioned 25 m from the railway in 2012 and 2013, and 12.5, 25, 50, and 100 m from the railway in 2017. A-weighted sound pressure level with a 1 s time constant was measured every 1 s during the passage of a Shinkansen train. $L_{A,Smax}$ or energy averaged indices, such as $L_{Aeq,24h}$ and L_{den}, were calculated from the level records.

Furthermore, distance reduction equations were formulated using the measurement in 2017. Noise exposure levels were estimated at the facades of the houses with the distance reduction equations.

2.3 Analysis

Because the main objective of this study is to investigate the relationship between the number of Shinkansen noise events and annoyance, a multiple logistic regression analysis was applied with a dichotomous variable of "very annoyed (disturbed) or not" as the dependent variable and $L_{A,Smax}$, number of Shinkansen noise events, length of residence, age, and sex as the independent variables. All statistical analyses were performed with JMP 14.

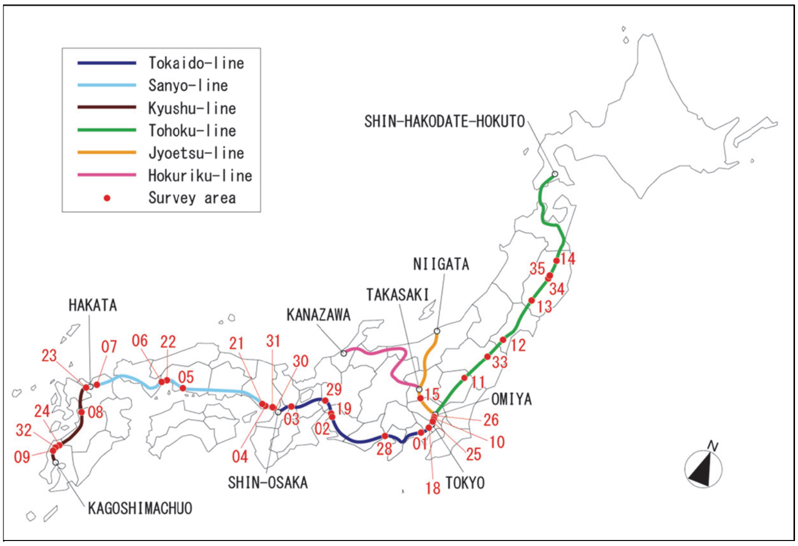

Figure 1 – Survey areas along Shinkansen railway lines

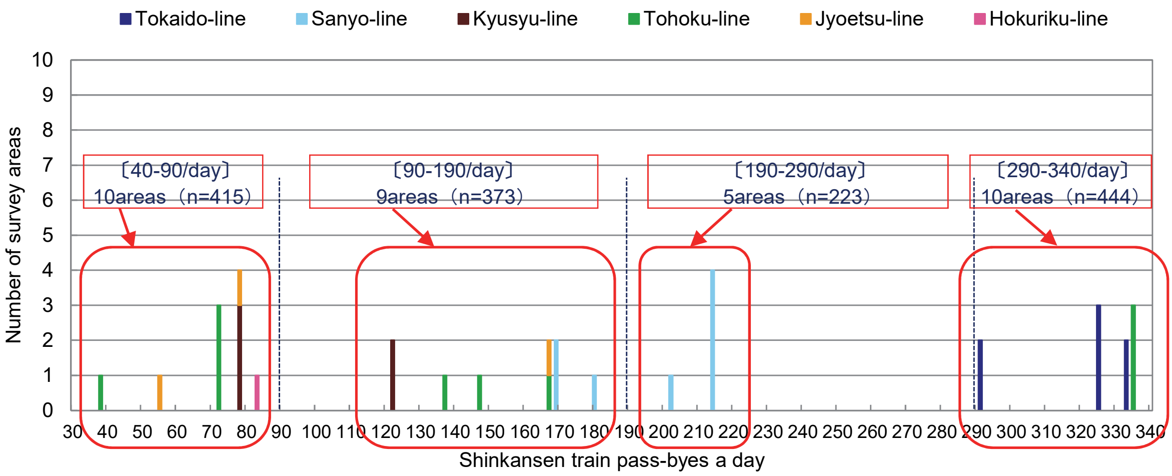

Figure 2 – Number of survey areas according to the number of train pass-byes per day

3. RESULTS

3.1 Demographic Variables

Table 2 shows the distribution of demographic variable. 75 % of respondents had lived in their homes for more than 10 years, approximately two thirds of respondents were 60 years old or more, and there were more females than males. There seems to be little difference in %VA between the length of residence and sex. %VA for residents in their 40s to 60s is higher than for other generations.

3.2 Noise Levels

$L_{A,Smax}$ and L_{den} at the facades of houses ranged from 53 to 84 dB and from 36 to 66 dB, respectively. The numbers of respondents in the ranges of $L_{A,Smax} < 65$, $65 \le L_{A,Smax} < 70$, $70 \le L_{A,Smax} < 75$, and $75 \le L_{A,Smax}$ were 739 (51%), 449 (31%), 202 (14%), and 65 (4%), respectively (see

Table 3). The environmental quality standard values are 70 dB and 75 dB depending on the area characteristic. Because various noise countermeasures have been taken along the railways, the number of respondents exposed to more than 75 dB is currently low.

Table 2 – Distribution of demographic variables

Item	Category	sample (%)	% Very Annoyed
Resident	Y<10	24.7	28.6
	10≤Y	75.3	28.1
Age	<30	5.2	21.9
	30s	8.5	29.2
	40s	10.9	33.1
	50s	12.4	29.3
	60s	26.8	32.4
	70s	36.2	21.6
Sex	female	57.5	25.1
	male	42.5	29.6

Table 3 – Sample size according to maximum noise level

		Number of Shinkansen noise events			
Item	Category	40-90/day	90-190/day	190-290/day	290-340/day
Sample Size	$L_{A,smax}$ <65	201	177	127	234
	65≤ $L_{A,smax}$ <70	147	103	51	148
	70≤ $L_{A,smax}$ <75	60	61	29	52
	75≤ $L_{A,smax}$	7	32	16	10

3.3 Relationship between Noise Exposure and Annoyance

Figure 3 (a) and (b) show the relationship between $L_{A,Smax}$ and %VA, and between L_{den} and %VA, respectively. There is no clear difference between the two relationships; %VA increases as noise exposure increases in both.

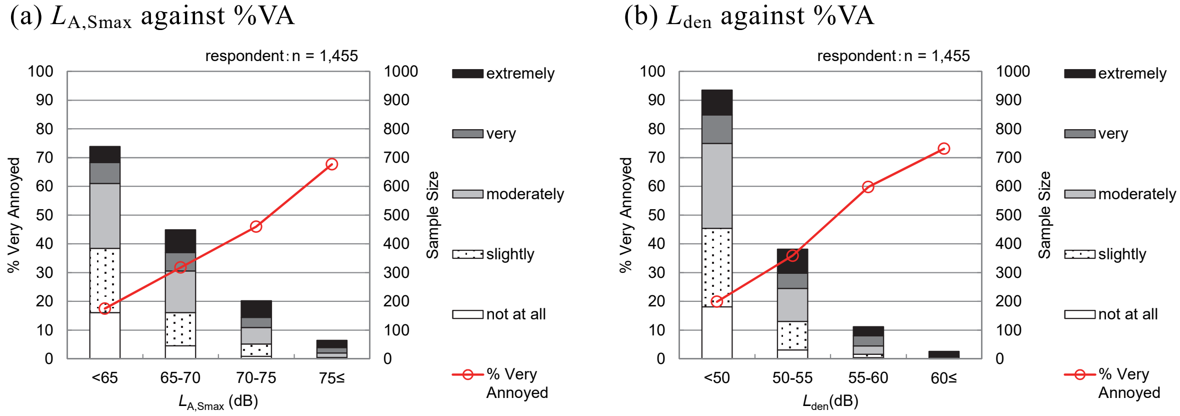

Figure 3 – Exposure-%VA relationships

3.4 Relationship between Noise Exposure and Listening / Sleep Disturbances

%D for listening is 30 % or more in the range of 70-75 dB for $L_{A,Smax}$ and in the range of 55-60 dB for L_{den} (see Figure 4). %VSD is less than 10% over the whole noise exposure range (see Figure 5). Sleep disturbance is much less than listening disturbance because Shinkansen trains are operated only from 06:00 to 24:00.

(a) $L_{A,Smax}$ against %D for listening (b) L_{den} against %D for listening

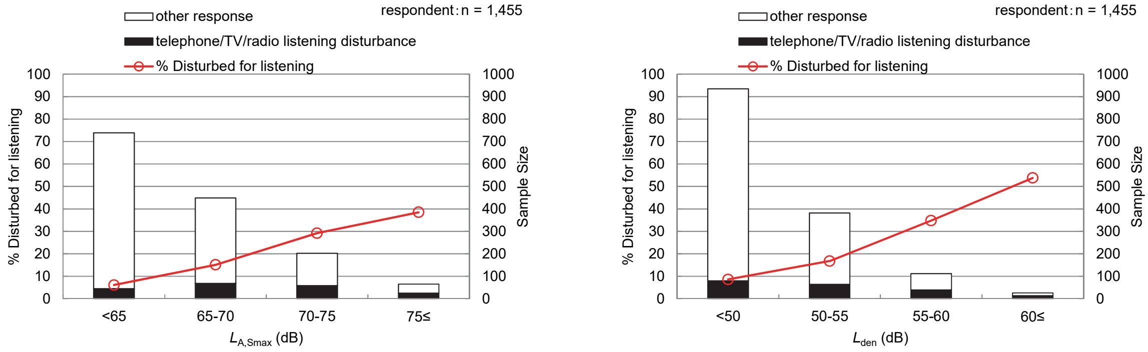

Figure 4 – Exposure-%D relationships

(a) $L_{A,Smax}$ against %VSD (b) L_{den} against %VSD

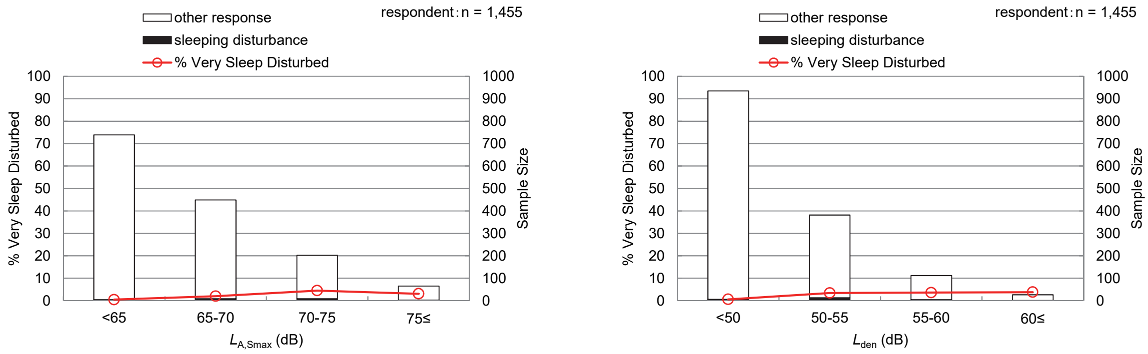

Figure 5 – Exposure-%VSD relationships

3.5 Effect of Number of Noise Events on Exposure–Annoyance Relationships

Figure 6 plots $L_{A,Smax}$ against %VA among the event number categories. %VA increases as the event number increases up to the range of 190 to 290, and then it decreases for the range of 290 to 340, as shown in Figure 6 (a). The data include extremely high %VA in Areas No. 4 (65%) and No. 5 (73%). Area No. 5 is in a valley, and it might be affected by echoing. However, it is unclear why %VA in Area No. 4 is so high. Figure 6 (b) shows the results excluding the two anomalous areas. Almost the same trend as in Figure 6 (a) is seen, but saturation appears to occur after approximately 300 events per day.

(a) %VA for all areas (b) %VA excluding No.4 and No.5

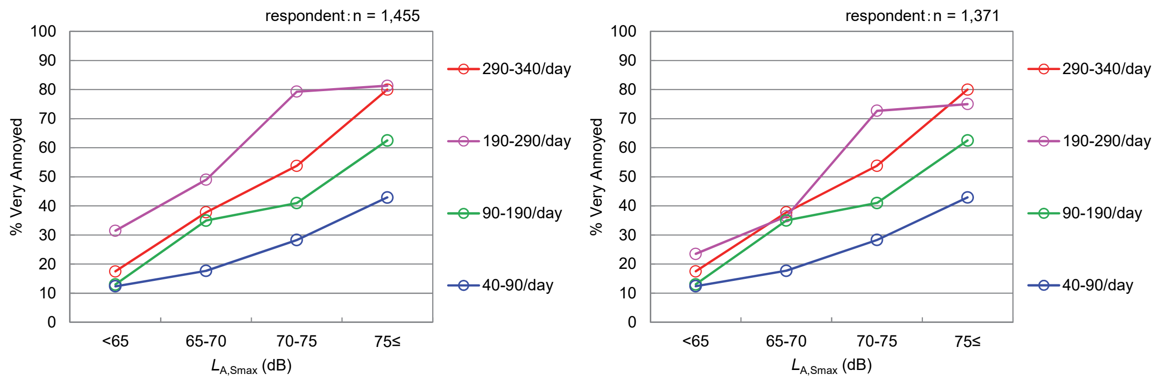

Figure 6 – %VA according the number of Shinkansen noise events

3.6 Effect of Number of Noise Events on Exposure–Annoyance Relationships

The results of multiple logistic regression analysis for annoyance are shown in Table 4. The maximum noise level ($L_{A,Smax}$) is significant because the odds ratio referring to $L_{A,Smax}$<65 dB increases as the noise level increases, and the lower value of the 95 % confidence interval is more than 1. The number of Shinkansen noise events is also significant. The odds ratio for 190-290/day, referring to 40-90/day, is largest, followed by 290-340/day and 90-190/day. The length of residence, age, and sex are not significant. The results of multiple logistic regression analysis for TV/radio listening disturbance are shown in Table 5. The maximum noise level ($L_{A,Smax}$) is significant in all ranges. The number of noise events is significant only in the 190-290/day and 290-340/day ranges. The results of multiple logistic regression analysis of sleep disturbance are shown in Table 6. $L_{A,Smax}$ is significant only in the range of 70-75 dB. The number of Shinkansen noise events is not significant.

Table 4 - Multiple logistic regression analysis of Annoyance (AUC=0.718)

Item	Category	Estimate	Standard error	p value	Odds ratio	Lower 95% CI	Upper 95% CI
Intercept		-2.646	0.363	<0.0001			
$L_{A,smax}$	$L_{A,smax}$ <65				1		
	65≤ $L_{A,smax}$ <70	0.898	0.151	<0.0001	2.454	1.825	3.299
	70≤ $L_{A,smax}$ <75	1.496	0.187	<0.0001	4.464	3.092	6.446
	75≤ $L_{A,smax}$	2.313	0.311	<0.0001	10.100	5.489	18.585
Number of Events	40-90/day				1		
	90-190/day	0.504	0.189	0.0076	1.656	1.143	2.399
	190-290/day	1.424	0.213	<0.0001	4.156	2.738	6.309
	290-340/day	0.824	0.178	<0.0001	2.280	1.608	3.231
Resident	Y<10				1		
	10≤Y	-0.027	0.180	0.8799	0.973	0.684	1.385
Age	<30				1		
	30s	0.266	0.383	0.4874	1.305	0.616	2.767
	40s	0.596	0.370	0.1074	1.814	0.879	3.746
	50s	0.464	0.379	0.2214	1.590	0.756	3.342
	60s	0.489	0.354	0.1673	1.631	0.815	3.263
	70s	0.026	0.357	0.9424	1.026	0.510	2.067
Sex	female				1		
	male	0.215	0.132	0.1048	1.240	0.956	1.607

Table 5 - Multiple logistic regression analysis of telephone/TV/radio listening disturbance (AUC=0.750)

Item	Category	Estimate	Standard error	p value	Odds ratio	Lower 95% CI	Upper 95% CI
Intercept		-3.941	0.584	<0.0001			
$L_{A,smax}$	$L_{A,smax}$ <65				1		
	65≤ $L_{A,smax}$ <70	1.194	0.219	<0.0001	3.299	2.147	5.068
	70≤ $L_{A,smax}$ <75	2.057	0.243	<0.0001	7.821	4.858	12.590
	75≤ $L_{A,smax}$	2.586	0.335	<0.0001	13.282	6.881	25.635
Number of Events	40-90/day				1		
	90-190/day	0.067	0.259	0.7965	1.069	0.643	1.776
	190-290/day	1.277	0.268	<0.0001	3.564	2.122	6.060
	290-340/day	0.672	0.235	0.0042	1.958	1.236	3.104
Resident	Y<10				1		
	10≤Y	0.071	0.241	0.769	1.073	0.669	1.723
Age	<30				1		
	30s	0.544	0.601	0.3659	1.723	0.530	5.598
	40s	1.143	0.578	0.0477	3.138	1.011	9.733
	50s	0.850	0.593	0.1520	2.339	0.731	7.483
	60s	0.699	0.569	0.2189	2.012	0.660	6.131
	70s	0.402	0.573	0.4829	1.495	0.486	4.595
Sex	female				1		
	male	-0.306	0.179	0.0868	0.736	0.519	1.045

Table 6 - Multiple logistic regression analysis of sleeping disturbance (AUC=0.695)

Item	Category	Estimate	Standard error	p value	Odds ratio	Lower 95% CI	Upper 95% CI
Intercept		-5.303	0.980	<0.0001			
$L_{A,smax}$	$L_{A,smax}$ <65				1		
	65≤ $L_{A,smax}$ <70	0.997	0.614	0.1041	2.711	0.814	9.023
	70≤ $L_{A,smax}$ <75	1.837	0.619	0.0030	6.278	1.865	21.127
	75≤ $L_{A,smax}$	1.447	0.896	0.1064	4.249	0.734	24.605
Number of Events	40-90/day				1		
	90-190/day	-0.428	0.672	0.5237	0.652	0.175	2.431
	190-290/day	0.726	0.604	0.2295	2.066	0.633	6.750
	290-340/day	0.236	0.557	0.6722	1.266	0.425	3.769
Resident	Y<10				1		
	10≤Y	0.278	0.660	0.6738	1.320	0.362	4.812
Age	<40				1		
	40s	0.518	0.949	0.5854	1.678	0.261	10.791
	50s	-0.126	1.091	0.9080	0.882	0.104	7.482
	60s	0.342	0.896	0.7025	1.408	0.243	8.152
	70s	0.319	0.907	0.7249	1.376	0.233	8.137
Sex	female				1		
	male	0.174	0.426	0.6825	1.190	0.516	2.745

4. DISCUSSION

The main objective of this study is to investigate the effects of event number on annoyance using data from socio-acoustic surveys on Shinkansen noise carried out in 2014 and 2017.

For $L_{A,Smax}$, %VA increases as the number of events increases up to 190-290/day and saturates afterwards. For 290-340/day, %VA decreases. This may be because %VA is extremely high in areas No. 4 and No. 5 along the Sanyo Shinkansen line. Though we cannot identify the reason why the annoyance in Area No. 4 is so high, Area No. 5 is in a valley and might be affected by echoing, i.e., the so called amphitheater effect described by Guski et al. [3]. Because energy averaged sound level is proportional to the logarithm of the event number, the trend of Figure 6 suggests that the annoyance caused by Shinkansen noise is well described by energy averaged sound level.

This strongly suggests that an increase in the number of noise events above a certain high number (saturation point) will not lead to an increase in annoyance. Rylander et al. [2] assumed that "at a large number of events, the number of events can no longer be discriminated (for instance, flickering of light or applying pressure on the skin with high frequency). The sensation is interpreted as one of continuous stimulus, even if the frequency of events is further increased."

Multiple logistic regression analysis of TV/radio listening disturbance shows that the number of noise events is insignificant for 90 ≤ N < 190 but significant for N ≥ 190. In the analysis of sleep disturbance, the number of noise events is not significant in all categories because there are usually no trains passing from 24:00 to 06:00. Though general annoyance is largely affected by the number of noise events, activity disturbances may be less affected by the number of noise events.

Almost all of the non-acoustic factors, such as sex, age, and the length of residence, are insignificant in annoyance and activity disturbances, except for people in their 40s in telephone/TV/radio listening disturbance. However, the odds ratio of age is the largest for people in their 40s to 60s. as well as van Gerven et al. [4].

5. CONCLUSIONS

In Japan, when the index for Environmental Quality Standards for Shinkansen Superexpress Railway Noise was established, the technical committee concluded that it was only necessary to estimate Shinkansen railway noise based on the maximum noise level for 100 to 250 Shinkansen train pass-byes per day. We investigated the effects of the number of noise events on annoyance using nation-wide social survey data on Shinkansen railways.

The findings of this study are as follows:

(i) For $L_{A,Smax}$, %VA increases as the number of pass-byes increases up to the range of 190-290/day and then saturates for 290-340/day.

(ii) Because the energy averaged sound level is proportional to the logarithm of event number, the trend of the $L_{A,Smax}$–%VA relationship suggests that the annoyance caused by Shinkansen noise is well described by the energy averaged sound level.

(iii) Though annoyance is largely affected by the number of noise events, activity disturbances such as TV/radio listening disturbance and sleep disturbance, may be less affected by the number of noise events.

We believe that considering the number of trains passing by is more effective for estimation of annoyance caused by Shinkansen noise than only the maximum noise level ($L_{A,Smax}$).

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