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Community tolerance level for transportation noises derived from the Socio-Acoustic Survey Data Archive, SASDA

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ABSTRACT

Socio-Acoustic Survey Data Archive (SASDA), established in 2011 under the Institute of Noise Control Engineering, Japan, is a data archive that accumulates social survey data on community responses to environmental noise throughout Japan. Exposure–response relationships and community tolerance level (L_{ct}), which is described in the latest version of ISO 1996-1, were calculated for each SASDA dataset. Among the noise sources, road traffic had the highest mean L_{ct} value, followed by conventional railways, high-speed railways, civil aircraft, and military aircraft, in descending order. Additionally, the L_{ct} values for road traffic and conventional railway noises decreased by about 5 dB and 10 dB, respectively, from 1994 to 2004. Differences of annoyance scales and/or decreasing of response rate may be possible explanations for this temporal trend, but future work is needed to comprehensively investigate possible causes. Furthermore, mean L_{ct} values for each noise source were compared with results from previous studies based on surveys conducted in western countries and Vietnam. Overall, mean L_{ct} values derived from the SASDA were lower than those in previous studies.

INTRODUCTION

Community tolerance level, L_{ct}, is defined in ISO 1996-1:2016 [1] as the day-night sound level at which 50% of the people in a particular community are predicted to be highly annoyed by noise exposure. The L_{ct} parameter is typically used to account for differences among sources and/or communities when predicting the percentage of individuals highly annoyed by noise exposure. Fidell et al. [2] calculated the values of L_{ct} for aircraft noise using data derived from social surveys conducted from the 1960s to the 2000s, and they presented the distribution and mean values of L_{ct} among the surveys. Similarly, Schomer et al. [3] calculated L_{ct} values for road traffic and railway noises, and Gjestland et al. [4] reported the results of L_{ct} comparisons between western countries and Vietnam for road traffic and aircraft noises. In the present study, in order to examine differences in annoyance responses among noise sources in Japan and compare the results with previous studies, exposure–response relationships and L_{ct} were estimated using datasets derived from the Socio-Acoustic Survey Data Archive (SASDA), and from other surveys that were conducted in recent years throughout Japan but have not been deposited with the SASDA.

METHODS

Dataset outline

The SASDA was established in 2011 under the Institute of Noise Control Engineering, Japan, and possesses more than 40 datasets from more than 20 surveys conducted throughout Japan [5]. From among these datasets, only the surveys that focused on transportation noise were included in the present analyses. Additionally, the datasets from social surveys conducted for high-speed railway noise [6, 7] and military aircraft noise [8] in recent years were also included, though these datasets are not deposited with SASDA.

Table 1 summarizes the datasets included in the present study. These surveys were conducted from 1994 to 2015, and the investigated areas were unevenly scattered throughout Japan. Response rates among the surveys conducted before the 2000s ranged from 60% to 80%, but response rates tended to decrease in recent years.

Every questionnaire survey included a question about noise annoyance using verbal scales, but the question wording, such as descriptors for annoyance evaluation and modifiers for the scale, differed among surveys. Furthermore, the number of points on the evaluation scales also differed, ranging from 4- to 7-point scales. The standardized 5-point verbal scale recommended by ICBEN team 6 and ISO/TS 15666 [9] was used in the surveys conducted since the early 2000s. Accordingly, the results from the datasets based on the ICBEN 5-point scale and those based on other scales are shown in the following analyses.

Japanese homes can be divided into three different types: detached wooden houses, low-/middle-rise apartment buildings, and high-rise apartment buildings. Sound insulation characteristics differ among these three types of homes, and the number of respondents living in detached houses was prominent in the data of SASDA. Accordingly, the following analyses include only the data from respondents living in detached houses.

L_{ct} calculation methodology

According to the method employed by Fidell et al. [2], the exposure–response relationship in each dataset can be estimated using Equation 1.

$$\mathrm{p}(\mathrm{HA}) = e^{-\mathrm{A}/m} \qquad (1)$$

Parameter *m*, which is an estimated noise level, is estimated using Equation 2.

$$m = \left(10^{(L_{\mathrm{dn}}/10)}\right)^{0\ 3} \qquad (2)$$

The community-specific constant *A* is a scalar variable describing a non-acoustic decision criterion, and its value in a given community is that which minimizes the root-mean-square error between the predicted and observed annoyance prevalence rates. The L_{ct} value is calculated from *A* in Equation 3.

$$L_{\mathrm{CT}} = 5.31 + 33.33 \log_{10} \mathrm{A} \qquad (3)$$

Although Taraldsen et al. [10] recommend a new method that can calculate L_{ct} with less uncertainty, the original method by Fidell et al. [2] is used in the present analyses.

Table 1: Datasets included in the present study

Dataset No.	Survey ID	Noise source	Survey period	Number of respondents	Response rate [%]
1	JPN002CR(1)	Conventional railway	1994–1995	456	80%
2	JPN002CR(2)			451	
3	JPN002CR(3)			427	
4	JPN002CR(4)			461	
5	JPN003RT	Road traffic	1994–1995	382	80%
6	JPN004HR	High-speed railway	1995–1996	855	72%
7	JPN005RT	Road traffic	1996	350	76%
8	JPN006CR	Conventional railway	1997	179	79%
9	JPN007RT	Road traffic	1997–1998	404	64%
10	JPN009RT	Road traffic	1998	312	70%
11	JPN011RT	Road traffic	2000–2006	1586	-
12	JPN012CR(1)	Conventional railway	2001	487	69%
13	JPN012CR(2)			480	
14	JPN012CR(3)			454	
15	JPN013HR	High-speed railway	2001–2003	865	57%
16	JPN014CR(1)	Conventional railway	2002	374	65%
17	JPN014CR(2)			381	64%
18	JPN014CR(3)			375	63%
19	JPN014CR(4)			392	64%
20	JPN015HR	High-speed railway	2003	715	66%
21	JPN016RT	Road traffic	2003–2004	272	63%
22	JPN017CR	Conventional railway	2003–2006	965	-
23	JPN018HR	High-speed railway	2003–2006	1063	-
24	JPN019CA	Civil aircraft	2003–2006	471	-
25	JPN020MA	Military aircraft	2003–2006	834	-
26	JPN021MS(RT)	Road traffic	2004–2006	623	49%
27	JPN021MS(CR)	Conventional railway	2004–2006	626	49%
28	JPN022HR	High-speed railway	2005	138	-
29	JPN023CA	Civil aircraft	2006	412	53%
30	2014_HR	High-speed railway	2013	288	45%
31	2017_HR	High-speed railway	2011	523	30%
32	2016_MA(1)	Military aircraft	2015	470	20%
33	2016_MA(2)			580	24%
34	2016_MA(3)			635	22%
35	2016_MA(4)			473	21%
36	2016_MA(5)			356	20%
37	2016_MA(6)			382	20%
38	2016_MA(7)			491	18%

In previous studies, L_{ct} was given by pairs of representative L_{dn} values and percent highly annoyed (%HA) at each interviewing site. However, area information regarding interviewing sites was not necessarily available for all data used in this study. Therefore, in the following analyses, %HA estimates for each L_{dn} category recorded in 5-dB increments were used for calculating L_{ct}, though this approach has the disadvantage of lacking area characteristics.

The A-weighted equivalent continuous sound pressure level, $L_{Aeq,24h}$, was used as the noise exposure metric in some datasets for road traffic noise and conventional railway noise. As such, the L_{dn} values for these datasets were estimated by adding 4 dB to $L_{Aeq,24h}$ based on the relationship between $L_{Aeq,24h}$ and L_{dn} in other surveys. Schomer et al. [3] estimated L_{dn} by adding 3 dB to $L_{Aeq,24h}$ for road traffic noise and 4 dB for railway noise, respectively, in similar cases.

Following many previous studies [11], a response scale cut-off point of 72% was used as the definition of highly annoyed in the present study.

RESULTS AND DISCUSSION

Exposure–response relationships in each dataset

The exposure–response relationships between L_{dn} and %HA were estimated from each dataset using Equations (1) and (2), and Figure 1 presents these relationships for each noise source. The coefficients of determination, R^2, for each model were high, exceeding 0.80 in most datasets. Although a few datasets did not fit the model, as demonstrated by the lowest R^2 value of 0.02 for one of the high-speed railway datasets, L_{ct} was calculated without excluding these datasets in the following analyses, consistent with the methodology of previous studies. The red curves and red filled data points in Figure 1 indicate the exposure–response relationships and observed survey data using the ICBEN 5-point verbal scale. The prevalence rate of individuals highly annoyed according to surveys using the ICBEN 5-point scale appeared higher than that using other annoyance scales.

Comparison of L_{ct} among noise sources

Table 2 shows the L_{ct} values of each dataset, and Figure 2 presents the distributions of L_{ct} for each noise source. The L_{ct} distributions clearly differed among noise sources, and the modes of L_{ct} for road traffic, conventional railway, high-speed railway, and military aircraft noises were 75–80 dB, 65–70 dB, 60–65 dB, and 50–55 dB, respectively. The L_{ct} values from the two surveys of civil aircraft noise were located within the 55–60-dB noise class.

Table 3 and Figure 3 present the L_{ct} mean and standard deviation values for each noise source. The mean L_{ct} value was the highest for road traffic, followed by conventional railway, high-speed railway, civil aircraft, and military aircraft noises, in descending order. The difference in mean L_{ct} between road traffic and conventional railway was about 5 dB, although ISO 1996-1:2016 Annex E [1] indicates that the difference in mean L_{ct} between road traffic and high-vibration conventional railway is 2.5 dB. Because the data in the present study are composed of only respondents living in detached houses, this larger discrepancy in the Japanese data may be a consequence of the vulnerability of detached houses near railroads to vibrations from trains. According to ISO 1996-1:2016 Annex A [1], limited data suggest quite large differences in the annoyance response rate between high-speed railway and conventional railway noises. In this study, the differences in mean L_{ct} between high-speed railway and road traffic and between conventional railway and road traffic were about 10 dB and 5 dB, respectively. The present results support the suggestion of positive adjustment to conventional railway noise for high-speed railway noise. The differences in mean L_{ct} between road traffic and civil aircraft and between road traffic and military aircraft were about 17 dB and 25 dB, respectively. These differences were quite larger than the value of typical level adjustment for aircraft noise to road traffic noise, that is, 5–8 dB, as indicated by ISO 1996-1:2016 Annex A [1].

The mean L_{ct} values that were calculated from the survey using the ICBEN 5-point verbal scale for road traffic, conventional railway, and high-speed railway noises were slightly lower than those estimated from the all datasets shown in Table 2. These differences are discussed later, incorporating temporal trends in L_{ct}.

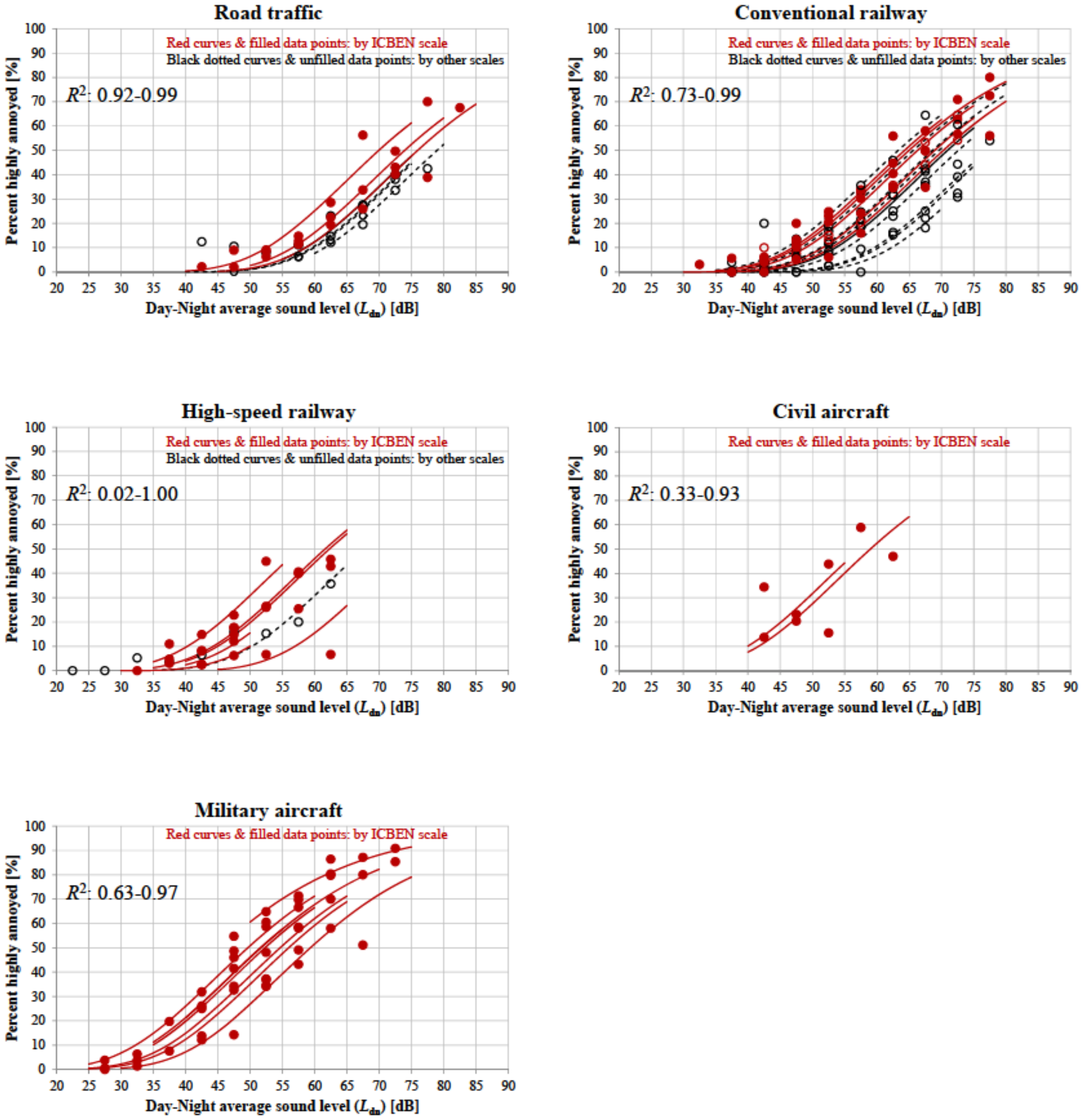


Figure 1: Exposure–response relationships between L_{dn} and %HA for each noise source and in each data-set derived from the SASDA and other Japanese surveys. Red curves and filled data points indicate the surveys that used the ICBEN 5-point verbal scale, and black dotted curves and unfilled data points indicate the surveys that used other scales.

Table 2: Annoyance scales and L_{ct} values from each survey

Dataset No.	Survey ID	Descriptors	Point scale	L_{ct} [dB]	R^2
1	JPN002CR(1)	annoyed	4-point	71.0	0.96
2	JPN002CR(2)	annoyed	5-point	72.6	0.94
3	JPN002CR(3)	annoyed	6-point	77.6	0.90
4	JPN002CR(4)	annoyed	7-point	77.0	0.89
5	JPN003RT	annoyed	4-point	77.0	0.93
6	JPN004HR	unbearable	5-point	67.6	0.91
7	JPN005RT	annoyed	4-point	76.0	0.93
8	JPN006CR	unbearable	5-point	79.6	0.88
9	JPN007RT	annoyed	4-point	79.0	0.94
10	JPN009RT	unbearable	5-point	77.3	0.95
11	JPN011RT	bothered, disturbed, or annoyed	5-point ICBEN	76.0	0.92
12	JPN012CR(1)	annoyed	4-point	69.6	0.89
13	JPN012CR(2)	bothered, disturbed, or annoyed	4-point	63.3	0.90
14	JPN012CR(3)	bothered, disturbed, or annoyed	5-point ICBEN	64.3	0.73
15	JPN013HR	bothered	5-point ICBEN	61.6	0.98
16	JPN014CR(1)	uncomfortable	5-point ICBEN	69.0	0.99
17	JPN014CR(2)	annoyed	5-point ICBEN	66.3	0.97
18	JPN014CR(3)	bothered, disturbed, or annoyed	5-point ICBEN	65.6	0.97
19	JPN014CR(4)	bothered	5-point ICBEN	68.6	0.92
20	JPN015HR	bothered, disturbed, or annoyed	5-point ICBEN	57.6	0.96
21	JPN016RT	bothered, disturbed, or annoyed	5-point ICBEN	74.0	0.93
22	JPN017CR	bothered, disturbed, or annoyed	5-point ICBEN	65.0	0.99
23	JPN018HR	bothered, disturbed, or annoyed	5-point ICBEN	62.3	0.96
24	JPN019CA	bothered, disturbed, or annoyed	5-point ICBEN	59.0	0.33
25	JPN020MA	bothered, disturbed, or annoyed	5-point ICBEN	45.3	0.92
26	JPN021MS(RT)	bothered	5-point ICBEN	70.0	0.93
27	JPN021MS(CR)	bothered	5-point ICBEN	70.3	0.96
28	JPN022HR	bothered, disturbed, or annoyed	5-point ICBEN	74.3	0.02
29	JPN023CA	bothered, disturbed, or annoyed	5-point ICBEN	57.3	0.93
30	2014_HR	bothered, disturbed, or annoyed	5-point ICBEN	64.3	1.00
31	2017_HR	bothered, disturbed, or annoyed	5-point ICBEN	67.3	0.80
32	2016_MA(1)	bothered, disturbed, or annoyed	5-point ICBEN	51.6	0.96
33	2016_MA(2)	bothered, disturbed, or annoyed	5-point ICBEN	59.3	0.88
34	2016_MA(3)	bothered, disturbed, or annoyed	5-point ICBEN	54.6	0.96
35	2016_MA(4)	bothered, disturbed, or annoyed	5-point ICBEN	52.3	0.63
36	2016_MA(5)	bothered, disturbed, or annoyed	5-point ICBEN	49.6	0.97
37	2016_MA(6)	bothered, disturbed, or annoyed	5-point ICBEN	51.6	0.81
38	2016_MA(7)	bothered, disturbed, or annoyed	5-point ICBEN	56.0	0.93

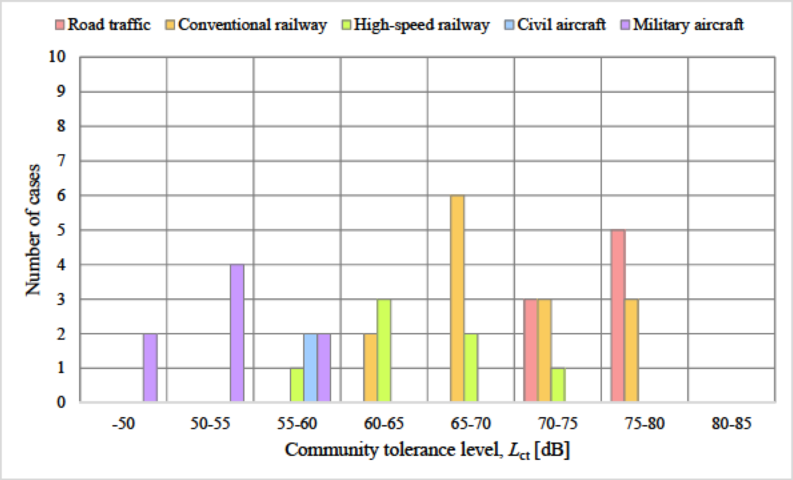


Figure 2: Distributions of L_{ct} values from each noise source (*N* = 39 total, 8 road traffic, 14 conventional railway, 7 high-speed railway, 2 civil aircraft, and 8 military aircraft survey datasets)

Table 3: Mean L_{ct} values among noise sources

		All	**Road traffic**	**Conventional railway**	**High-speed railway**	**Civil aircraft**	**Military aircraft**
All datasets	Mean	66.0	75.2	70.0	65.0	58.2	52.5
	S.D.	9.16	2.89	5.15	5.36	-	4.22
	N	39	8	14	7	2	8
ICBEN scale only	Mean	62.0	73.3	67.0	64.6	58.2	52.5
	S.D.	8.22	3.06	2.28	5.74	-	4.22
	N	26	3	7	6	2	8

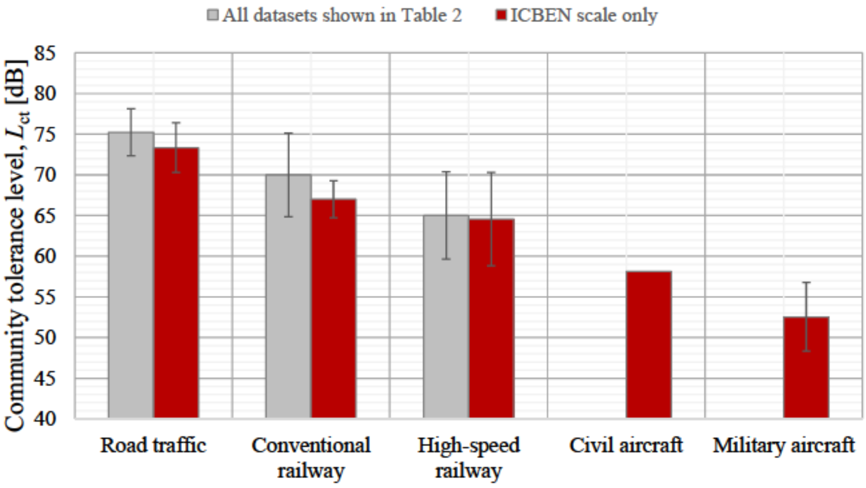


Figure 3: Comparison of mean L_{ct} values among noise sources, with error bars indicating standard deviations

Temporal trends in L_{ct} values among road traffic and conventional railway datasets

Some previous studies [12, 13] have shown that the annoyance of residents at a given aircraft noise exposure level appeared to increase over the years, and Fidell et al. [2] similarly demonstrated a small decrease over time in L_{ct} for aircraft noise of 0.2 dB per year from about 1960 to 2005. It has been assumed that the increasing annoyance rate over the years was related to abrupt acoustic changes, (e.g., those resulting from an airport expansion), differences among study designs (e.g., survey method, questionnaire annoyance scale, and response rate), characteristics of respondents, cultural differences, and so on. Alternatively, the tolerance within communities for aircraft noise may have decrease over time. Janssen et al. [13] reported that the heterogeneity of the annoyance scale used in each study statistically accounted for their observed trend. Gjestland et al. [3] proposed that the trend is caused by abrupt changes in the aircraft noise situation, as many recent aircraft noise annoyance studies have been conducted in the context of a change in the noise situation. Many previous studies have shown that such abrupt changes affect the annoyance prevalence rate [14–16]. Gelderblom et al. [17] investigated the effect of such abrupt changes on the trend by adding new datasets conducted in recent years to the database assembled by Fidell et al. [2] and showed that tolerance for aircraft noise does not decrease over time, but changes in aircraft noise situations significantly affect this trend.

In the present analysis, temporal trends in L_{ct} for road traffic and conventional railway noises were examined because there are few aircraft noise datasets deposited in SASDA. However, the trend for road traffic noise shown in ISO 1996-1:2016 [1] is not clearly downwards. Because the response rates and the information about changes in noise situations were not necessarily available for all datasets in the SASDA, the trends were examined considering only differences in the annoyance scales, that is, whether the ICBEN 5-point scale was used or not. These results are shown in Figures 4 and 5. The values of L_{ct} decreased about 5 dB and 10 dB for road traffic noise and conventional railway noise, respectively. Additionally, the surveys conducted after the 2000s have used the ICBEN 5-point verbal scale, while those conducted before the 2000s used other evaluation scales. Furthermore, as is shown in Table 1, response rates also did seem to decrease in recent years. Accordingly, future work is needed to comprehensively investigate possible causes, such as changes in annoyance scales, response rates, and noise situations. Additional datasets, especially those produced in recent years, must be included in analyses in order to accomplish this goal.

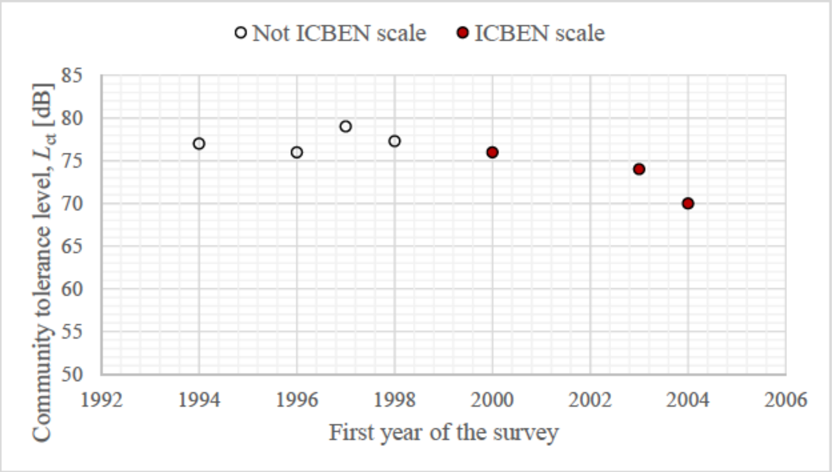


Figure 4: Temporal trends in L_{ct} values for road traffic noise between 1994 and 2004

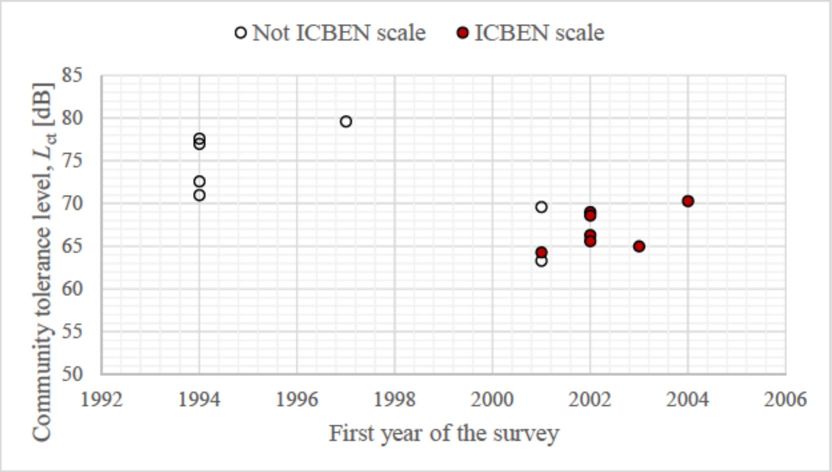


Figure 5: Temporal trends in L_{ct} values for conventional railway noise between 1994 and 2004

Comparison with previous studies

Figure 6 shows the distributions of L_{ct} from surveys conducted in Europe and North America that were considered in previous studies [2, 3] with L_{ct} values from Japanese and Vietnamese surveys added.

Road traffic noise

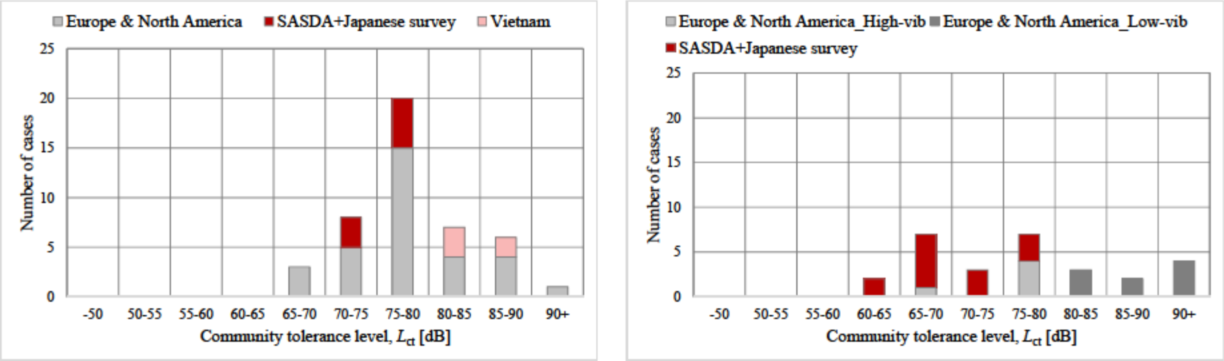
Schomer et al. [3] reported that the mean L_{ct} value for road traffic noise among 34 surveys was 78.3 dB. This mean value included results from the JPN005RT and JPN007RT datasets, which are also included in the SASDA. In order to compare the noise tolerance between Japan and other countries, the mean L_{ct} value was recalculated excluding the L_{ct} value from the two Japanese surveys, but the mean value was unchanged by this exclusion. As shown in Table 3, the mean L_{ct} value for road traffic noise within the Japanese datasets was 75.2 dB, which is about 3 dB lower than L_{ct} for other countries. Gjestland et al. [4] reported that the mean L_{ct} value for road traffic noise among five cities in Vietnam was 84.7 dB. The surveys conducted in the five cities each used the ICBEN 5-point scale. The mean L_{ct} value among Japanese surveys conducted using the ICBEN 5-point scale was 73.3 dB, which is about 10 dB lower than the mean L_{ct} in Vietnam.

Conventional railway noise

Schomer et al. [3] reported the mean L_{ct} for conventional railway noise among 16 datasets, and the mean L_{ct} among 6 datasets for which high levels of vibration and/or rattles were reported was 75.8 dB. Because the calculation of this mean value included results from the JPN002CR dataset, which is also included in the SASDA, the mean L_{ct} was recalculated excluding the L_{ct} value from the Japanese survey, which was 76.0 dB. As shown in Table 3, the mean L_{ct} value for conventional railway noise in Japanese datasets was 70.0 dB, which is 6 dB lower than mean L_{ct} values of other countries.

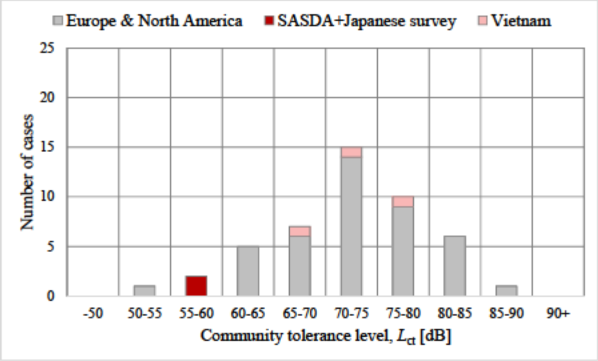
Civil aircraft noise

Fidell et al. [2] reported that the mean L_{ct} value for aircraft noise among 43 surveys was 73.3 dB, and Gjestland et al. [4] reported that the mean L_{ct} for aircraft noise among three cities in Vietnam was 72.2 dB. These mean L_{ct} values were almost identical. However, the mean L_{ct} value for civil aircraft noise among Japanese datasets was 58.2 dB (Table 3), which is about 15 dB lower than L_{ct} values of other countries. Notably, the Japanese results are derived from very few number of survey (i.e., N = 2), so analyses with additional surveys are needed.



Road traffic

Conventional railway



Civil aircraft

Figure 6: Distributions of L_{ct} values by surveys conducted in Europe and North America with Japanese and Vietnamese survey data added

CONCLUSIONS

The L_{ct} values of the Japanese datasets revealed several notable trends. The mean L_{ct} value of road traffic was the highest, followed by those of conventional railway, high-speed railway, civil aircraft, and military aircraft, in descending order. The differences between the mean L_{ct} value of road traffic and those of conventional railway, high-speed railway, civil aircraft, and military aircraft were about 5 dB, 10 dB, 17 dB, and 25 dB, respectively. The difference in mean L_{ct} value between road traffic and conventional railway was about 5 dB, though ISO 1996-1:2016 Annex E [1] indicates that the difference in mean L_{ct} between road traffic and high-vibration conventional railway was 2.5 dB. Because the data in the present study are derived only from respondents living in detached houses, the larger difference in the Japanese data may be explained by the vulnerability of detached houses near railroads to vibration caused by trains. ISO 1996-1:2016 Annex A [1] also indicates (based on limited data) large differences in the annoyance response rate between high-speed railway and conventional railway noises. The present results support a positive adjustment to conventional railway for high-speed railway noise. The differences between the mean L_{ct} value of road traffic and that of civil aircraft noises and between the mean L_{ct} value of road traffic and that of military aircraft noises were quite larger than the value of typical level adjustments for aircraft noise to road traffic noise, that is, 5–8 dB according to ISO 1996-1:2016 Annex A [1].

Temporal trends in L_{ct} values for road traffic and conventional railway noises were examined, revealing that the L_{ct} values for road traffic noise and conventional railway noise decreased about 5 dB and 10 dB, respectively, from 1994 to 2004. However, the surveys conducted after the 2000s used the ICBEN 5-point verbal scale, while those conducted before the 2000s used other evaluation scales. This suggests that differences in wording and/or modifications of annoyance scales are possible explanations for this trend, but future research is needed to comprehensively investigate possible causes, such as changes in annoyance scales, response rates, and noise situations.

The L_{ct} values derived from the SASDA were compared with those from Europe, North American, and Vietnam. The mean L_{ct} value for road traffic noise from Japanese datasets was about 3 dB lower than L_{ct} values from the surveys conducted in Europe and North America, and about 10 dB lower than L_{ct} values from the surveys conducted in Vietnam. The mean L_{ct} for conventional railway noise from the Japanese datasets was 6 dB lower than L_{ct} values from the European and North American surveys for which high levels of vibration and/or rattles were reported. Although further investigations with additional data are required, the mean L_{ct} value for aircraft noise from Japanese datasets was about 15 dB lower than L_{ct} values from the European, North American, and Vietnamese surveys.

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