Structural equation modeling with relations between disturbance and annoyance reactions due to transportation noise

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ABSTRACT

We have conducted secondary analysis of data in the Socio-Acoustic Survey Data Archive (SASDA) for Japan and investigated the relation between the disturbance reaction and noise exposure level, and that between the annoyance reaction and noise exposure level. These investigations will contribute to effective future noise policy. A SASDA subcommittee is planning to investigate the relationships among the noise exposure level, disturbance reaction, annoyance reaction and evaluation of the living environment. As a preliminary step toward the investigation, we investigated the relation among the noise exposure level, disturbance reaction and annoyance reaction in a covariance structure analysis using data that we collected in residential areas exposed to mixed noise from road traffic and a conventional railway.

Conventional railway noise was apt to cause acitivity disturbance, such as disturbances to listening, and this generated strong annoyance when compared with road traffic noise. The characteristics of the fluctuating level of conventional railway noise—a sudden increase and and then a constant high for a while—is a probable explanation of this result. Road traffic noise, in contrast, was not only a activity disturbance but also had health impacts such as the disturbance of sleep and thus induced annoyance. This was probably because there was road traffic noise around midnight.

INTRODUCTION

The Socio-Acoustic Survey Data Archive (SASDA) Subcommittee of the Institute of Noise Control Engineering of Japan (INCE/Japan) (Yokoshima et al. 2011-1, 2011-2) has conducted secondary analysis of data in its archive and investigated the relation between the disturbance reaction and level of noise exposure(Ota et al. 2013), and that between the annoyance reaction and level of noise exposure (Yokoshima et al. 2012). These investigations are to contribute to effective future noise policy. The subcommittee is also planning to investigate the relation among the noise exposure level, disturbance reaction, annoyance reaction and evaluation of the living environment. As a preliminary step to the investigation, the authors investigated the relation among the noise exposure level, disturbance reaction and annoyance reaction employing covariance structure analysis and data that the authors have collected in residential areas exposed to the mixed noise of road traffic and a conventional railway. We introduce the result of the covariance structure analysis in this paper.

OUTLINE OF THE SURVEY

Questionnaire survey

A social survey on the reactions of the community to road traffic noise and conventional railway noise was carried out in 22 residential areas of Kanagawa Prefecture, located within 150 meters from a main road and a conventional railway. Figure 1 shows an example of survey sites.

A questionnaire survey was conducted in October 2004 - 2006 for 1343 detached houses and 1618 apartments. Each house or apartment had one respondent aged 18 years or over. The questionnaire forms were posted directly and recovered by mail. Table 1 is an outline of the questionnaire form. The questionnaire form was titled “Questionnaire Survey about the Environment of Residential Areas and Houses”. The title aimed to avoid excessive specific concerns of noise from the respondents. The main questions about noise were as follows.

Q5 – Annoyance evaluation (five levels: not annoyed at all, slightly annoyed, moderately annoyed, very annoyed, extremely annoyed) of sounds from nine sources; e.g., “road traffic sounds” and “conventional railway sounds”.

Q6, 7 – Frequency (five levels: not at all, not much, sometimes, often, frequently) of nuisances (eight items: being startled, suffering poor health, disturbance while falling asleep, being woken, disturbance while listening to TV/radio, disturbance while conversing, reluctance to open windows, disturbance while resting) caused by road traffic noise and conventional railway noise.

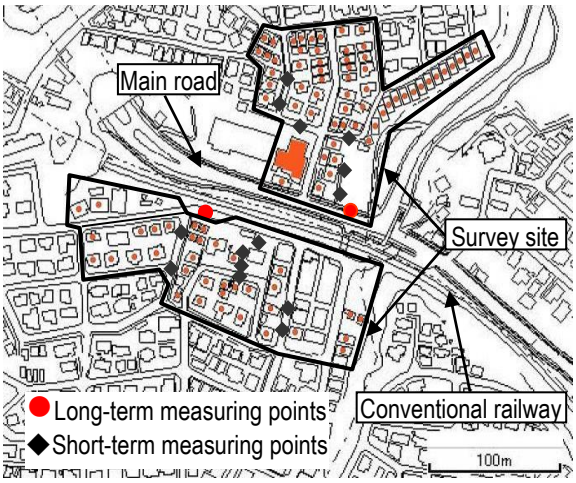

Figure 1: Example of a survey area and measurement points.

Table 1: Outline of the questionnaire sheet

	Question	Number of items	Answering method
Q1	Evaluation of satisfaction with the environment	28	Five levels
Q2	Important items among the 28 items of Q1	28	Unlimited choices
Q3	Most important items among the 28 items of Q1	28	Five or fewer choices
Q4	Overall evaluation of the living environment	5	Five levels
Q5	Evaluation of the annoyance caused by each sound source	9	Five levels
Q6	Frequency of nuisances caused by road traffic noise	8	Five levels
Q7	Frequency of nuisances caused by conventional railway noise	8	Five levels
Q8	Evaluation of the annoyance caused by each vibration source	6	Five levels
Q9	Actions considering the environment	6	Three levels
Q10	Fact sheet on the respondent’s house	7	
Q11	Fact sheet on the respondent	7	
Q12	Free expression of opinions		

Noise measurement

Noise was measured from October to December in the years from 2004 to 2006. In this study, L_{Aeq} was used as the index of noise exposure.

Figure 1 shows the locations of noise measurement points.

L_{Aeq} of road traffic noise was measured from 10:00 to 16:00 at long-term measuring points located within 30 m of the edge of a main road; this value is regarded as $L_{Aeq,24h}$. At the same time, L_{Aeq} was measured for 15–30 min at 10 to 15 short-term measuring points. Some of the short-term measuring points were set on the balcony, emergency stairs, and outdoor paths of apartments. $L_{Aeq,24h}$ at each short-term measuring point was estimated by correcting $L_{Aeq,24h}$ against the long-term measuring point by subtracting the difference in the simultaneous L_{Aeq} values between the measuring points.

Conventional railway noise was measured at long-term measuring points located 5–20 m from the center of the nearest railroad track. $L_{Aeq,24h}$ of conventional railway noise was estimated from the sound exposure level (L_{AE}) of 30–100 trains and daily train service numbers. At the same time, L_{AE} of 6–10 trains was measured at each short-term measuring point, and the average L_{AE} at each short-term measuring point was calculated. $L_{Aeq,24h}$ was corrected against the long-term measuring point by subtracting the difference in the simultaneous average L_{AE} between the short-term measuring point and the long-term measuring point. $L_{Aeq,24h}$ at each short-term measuring point was thus estimated.

Decay curves in each survey area were obtained for the above-mentioned $L_{Aeq,24h}$ (simply referred to as L_{Aeq} hereafter) at the long-term and short-term measuring points. L_{Aeq} at the dwelling of each respondent was estimated from the decay curves.

FACTOR ANALYSIS OF NUISANCES

Prior to structural equation modeling, factor analysis was conducted on the eight nuisance items listed in Table 2. The number of factors was determined by referring to the scree plot in Figure 2. Table 2 presents the results of factor analysis. In terms of the factor loading, factor 1 was interpreted as activity disturbance, such as a disturbance to listening or conversation. Factor 2 was interpreted as a health impact, such as being woken up or suffering poor health.

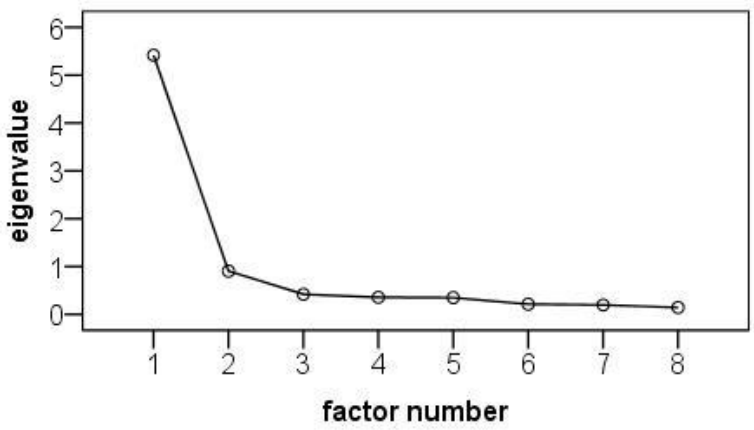

Figure 2: Scree plot of factor analysis.

Table 2: Factor loadings of factor analysis on eight nuisance items

	Factor 1	Factor 2
Disturbance while listening to TV/radio	0.963	−0.086
Disturbance while conversing	0.868	0.032
Disturbance while resting	0.750	0.097
Reluctance to open windows due to noise	0.722	0.211
Disturbance while falling asleep	0.001	0.884
Being woken	0.029	0.818
Suffering poor health	−0.001	0.798
Being startled	0.169	0.633

COVARIANCE STRUCTURE ANALYSIS

Hypotheses and path diagram

To analyze a causal relationship among the exposure level, nuisances, and annoyance, we made the following hypotheses and constructed the path diagram shown in Figure 3.

Nuisances are classified into two categories: activity disturbances and health impacts. The level of noise exposure affects activity disturbances and health impacts. Activity disturbances and health impacts affect the level of annoyance induced by a noise source, which comprises annoyance due to noise and that due to vibration.

The degree of influence among variables differs between road traffic noise and conventional railway noise, and between detached houses and apartments.

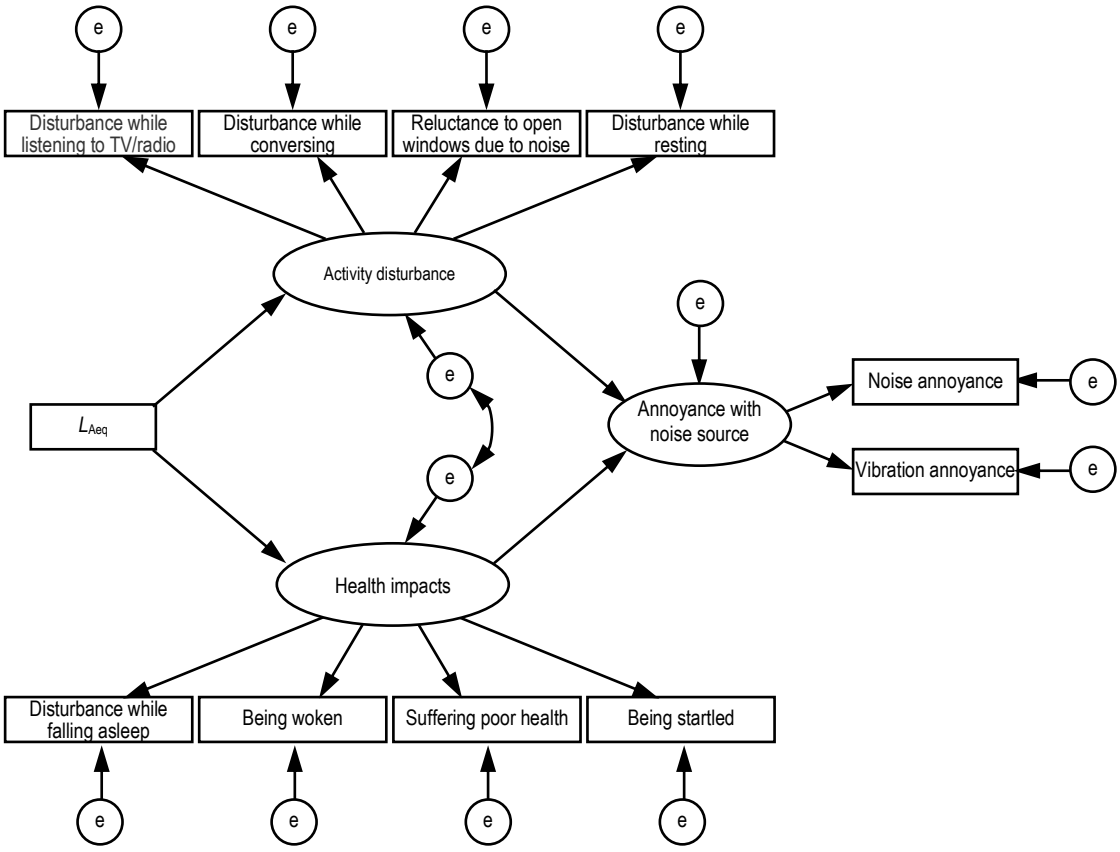

Figure 3: Path diagram of noise exposure, nuisances and annoyance.

It is desirable to include the vibration level with the noise level in the path diagram as a factor generating nuisances. However, the vibration exposure level in apartments was not obtained, and the vibration level was thus omitted in this analysis.

Data were classified into four categories, as shown in Table 3. All data of the four groups were used in covariance structure analysis at the same time. The analysis employed maximum likelihood estimation.

Table 3: Groups of data used in covariance structure analysis

	Dwelling type	Noise source	Sample number
Group 1	Detached house	Road traffic noise	606
Group 2	Apartment	Road traffic noise	688
Group 3	Detached house	Conventional railway noise	614
Group 4	Apartment	Conventional railway noise	699

Results of covariance structure analysis

Fit indices were GFI = 0.904, CFI = 0.941 and RMSEA = 0.057. We judged that the model was appropriate from these indices. Table 4 gives the standardized total effects.

Table 4: Standardized total effects

	L_{Aeq}	health impact	activity disturbance	annoyance
Health impact	0.44 / 0.28 0.49 / 0.34	-	-	-
Activity disturbance	0.49 / 0.54 0.63 / 0.50	-	-	-
Annoyance with noise source	0.46 / 0.46 0.58 / 0.46	0.45 / 0.40 0.29 / 0.29	0.53 / 0.64 0.69 / 0.73	-
Vibration annoyance	0.38 / 0.29 0.50 / 0.29	0.37 / 0.25 0.25 / 0.18	0.44 / 0.40 0.60 / 0.46	0.82 / 0.63 0.86 / 0.63
Noise annoyance	0.41 / 0.37 0.52 / 0.37	0.40 / 0.33 0.26 / 0.23	0.47 / 0.51 0.62 / 0.58	0.88 / 0.81 0.89 / 0.81
Being startled	0.35 / 0.20 0.39 / 0.25	0.78 / 0.72 0.80 / 0.75	-	-
Disturbance while resting	0.43 / 0.46 0.57 / 0.45	-	0.88 / 0.86 0.90 / 0.89	- -
Disturbance while falling asleep	0.37 / 0.25 0.45 / 0.31	0.83 / 0.87 0.91 / 0.92	-	-
Being woken	0.36 / 0.24 0.43 / 0.30	0.80 / 0.84 0.88 / 0.90	-	-
Suffering poor health	0.36 / 0.21 0.40 / 0.26	0.82 / 0.75 0.81 / 0.78	-	-
Reluctance to open windows due to noise	0.42 / 0.44 0.56 / 0.42	-	0.85 / 0.82 0.88 / 0.83	-
Disturbance while conversing	0.44 / 0.44 0.60 / 0.45	-	0.89 / 0.81 0.94 / 0.90	-
Disturbance while listening to TV/radio	0.43 / 0.45 0.58 / 0.44	-	0.88 / 0.84 0.92 / 0.88	-

detached, road / apartment, road
detached, rail / apartment, rail

Effects of the level of noise exposure on the occurrences of nuisances

Figure 4 shows the standardized direct effects of the level of noise exposure, L_{Aeq}, on the occurrences of activity disturbances and health impacts. The effect on activity disturbance was larger than that on health impacts as a whole. Activity disturbances were more easily generated than health impacts.

Health impacts were greater for detached houses than for apartments. Most Japanese detached houses have a wooden-frame construction while many Japanese apartments, especially the target buildings in this survey, have a reinforced-concrete construction. This difference in construction—specifically the difference in sound insulation and anti-vibration properties—is supposedly the main factor leading to the difference in direct effects on health impacts between detached houses and apartments.

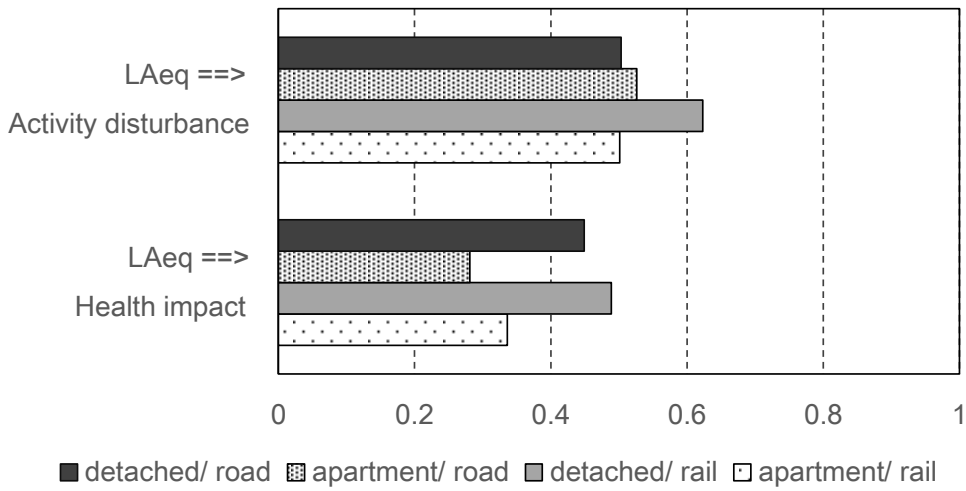

Figure 4: Standardized direct effects of L_{Aeq} on activity disturbance and health impacts.

Effects of nuisances on the annoyance with noise sources

Figure 5 shows the standardized direct effects of activity disturbances and health impacts on annoyance with noise sources. Overall, the effect of activity disturbances was larger than that of health impacts. Activity disturbances, such as disturbances while listening, seem to occur more frequently than serious health impacts, such as disturbances to sleep, which appears to be a major reason why activity disturbances have a greater effect.

In the case of railway noise, the effects of activity disturbances are larger and those of health impacts are smaller than the case for road traffic noise. This may be explained by the high frequency of activity disturbance caused by a large fluctuation of railway noise and the low frequency of sleep disturbance resulting from rare train services around midnight.

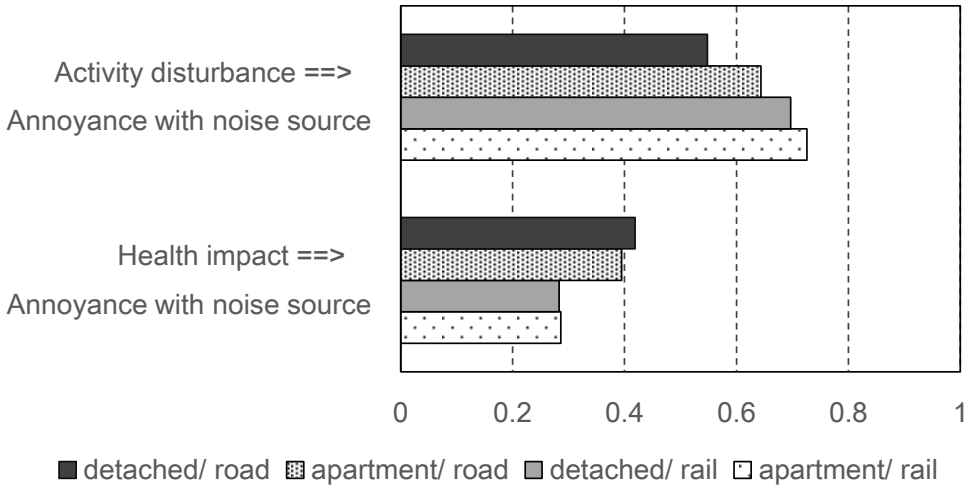

Figure 5: Standardized direct effects of activity disturbances and health impacts on annoyance generated by noise sources.

Total effect of the noise exposure on annoyance

Figure 6 shows the standardized total effects of L_{Aeq} on annoyance with noise sources. Additionally it also shows the standardized total effects of L_{Aeq} on the noise annoyance and vibration annoyance. Coefficients of determination of annoyance with noise source were 0.86 (detached/ road), 0.94 (apartment/ road), 0.89 (detached/ rail) and 0.94 (apartment/ rail) respectively.

The standardized total effect on annoyance with noise source in Group 3 (detached/ rail) was larger than that in other groups. Large fluctuation in railway noise and large railway vibrations are considered to partly explain the large effect of railway noise. Moreover, as described above, we suppose that the lower sound insulation and lower anti-vibration properties of detached houses increased the total effect.

The standardized total effect on vibration annoyance was similar to that on annoyance with noise annoyance. This apparent phenomenon might result from correlation between the noise exposure level and vibration exposure level.

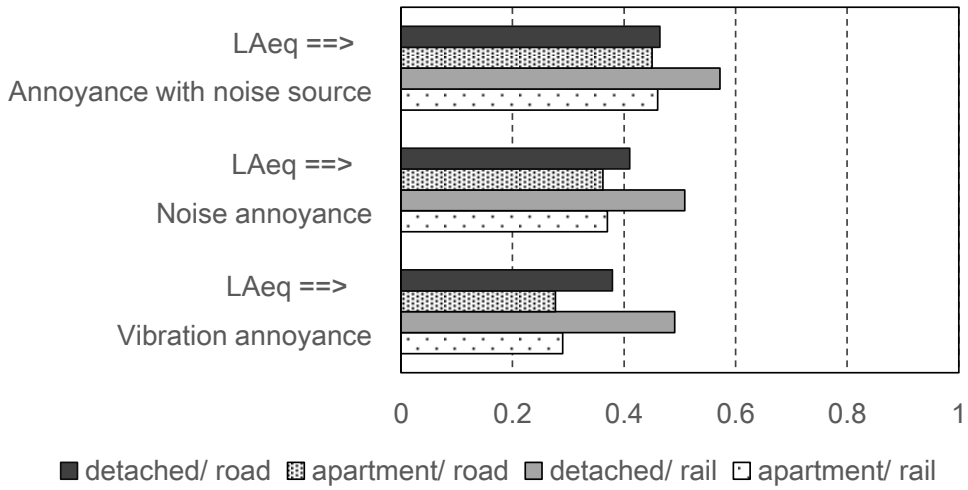

Figure 6: Standardized total effect of LAeq on annoyance with noise source.

CONCLUSION

The effects of noise exposure on disturbances of activities were larger than those on health impacts.

Conventional railway noise was apt to disturb activities such as listening, and generated strong annoyance. The characteristic fluctuation of the level of railway noise—a sudden increase and then a constant high—is a probable explanation of this result.

In the case of road traffic noise, not only nuisances but also health impacts, such as disturbance to sleep, generated annoyance. This was probably because there was road traffic noise around midnight.

Apartments were hardly affected by noise when compared with detached houses, owing to their better sound insulation and anti-vibration properties.

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