The effects of long-term exposure to railway and road traffic noise on subjective sleep disturbance

Jiyoung Hong
School of Mechanical and Aerospace Engineering and the Engineering Research Institute, Seoul National University, Room 105, Building 311, Seoul 151-744, Republic of Korea

Jaehwan Kim
School of Mechanical and Aerospace Engineering and the Engineering Research Institute, Seoul National University, Room 205, Building 44, Seoul 151-744, Republic of Korea

Changwoo Lim
Department of Environmental policy, Republic of Korea Air Force, P.O. Box 501-306, Bunam-ri, Sindoan-myeon, Gyeryong 321-929, Republic of Korea

Kyutae Kim
School of Mechanical and Aerospace Engineering and the Engineering Research Institute, Seoul National University, Room 205, Building 44, Seoul 151-744, Republic of Korea

Soogab Lee[a)]
School of Mechanical and Aerospace Engineering, Seoul National University, Room 1303, Building 301, Seoul 151-744, Republic of Korea

(Received 1 March 2009; revised 19 July 2010; accepted 31 August 2010)

The exposure-response relationships between subjective annoyance with sleep disturbance from railway trains and road traffic noise were established from an extensive social survey by CENVR (Center for Environmental Noise and Vibration Research) in Korea. The objectives of this research are to determine the long-term effects of noise on sleep and to compare the exposure-response relationships from different noise sources with those from other studies and to elucidate the effects of some modifying factors on subjective responses to noise. From an investigation of the percentage of a highly sleep-disturbed population (%HSD) in response to railway and road traffic noise, it was found that sleep is affected more by railway noise than by road traffic noise. The effects of non-acoustical factors on the responses were examined and sensitivity was shown to be a significant modifying factor, as it pertains to subjective sleep disturbance. A comparison of the response curves from an analysis of pooled data from predominantly European surveys by Miedema and Vos [Behav. Sleep Med. **5**, 1–20 (2007)] with the response curves from this survey showed more of a subjective sleep disturbance response in this survey to railway noise, whereas there was no significant difference in terms of a response to road traffic noise.
 [DOI: 10.1121/1.3493437]

PACS number(s): 43.50.Qp, 43.50.Rq, 43.50.Sr [BSF] Pages: 2829–2835

I. INTRODUCTION

Most of the complaints from populations living where transportation noise is serious mainly refer to annoyance and sleep disturbance. Numerous studies have been performed over the last 30 years in both a laboratory environment and the field. The effect of noise exposure on sleep is typically assessed in experimental research in controlled environments. The most popular method is to measure the physiological response of subjects by EEG (Electroencephalogram) recordings. Some researchers have conducted laboratory experiments to investigate behavioral awakening and arousal using EEG recordings.

In addition to EEG recordings, other methods, such as the measurement of body movements using an actimeter, clinical observation, and self-reported surveys have also been used in field studies. Some of this field research has examined the effects of road traffic and railway noise on sleep.[1–3] The effects of transportation noise have been reviewed with meta-analysis and secondary analysis based on the accumulated survey data.[4,5] Recently, Miedema reported newly updated relationships between noise levels and their corresponding responses using survey data most of which came from either European and or English speaking countries.[6,7] Their study showed that railway noise is less annoying and less sleep-disturbing than road traffic noise. This is reflected in the noise regulations of some European countries as the so-called ‘railway bonus’.

In contrast, a previous Korean study on annoyance response to transportation noise showed the opposite trend, in which railway noise was more annoying than road traffic noise.[8,9] This result is in good agreement with the results of related Japanese research on this subject.[10] With respect to

[a)]Author to whom correspondence should be addressed. Electronic mail: solee@snu.ac.kr

TABLE I. Information on the survey sites and the operation of noise sources.

	Type			
	Railway noise		Road traffic noise	
Location	Gyungbu/Honam railway lines		Principal roads, Expressways	
Total number of sites	18		17	
Number of passing vehicles during 22–07 h	$59 \leq N \leq 82$		$5725 \leq N \leq 37\,649$	
Composition (%)	Passenger	Freight	Light vehicles	Heavy vehicles
	44	56	69	31
Distance from noise sources	Number of sites			
$d < 100$ m	14		14	
$d > 100$ m	4		3	

sleep disturbance, some researchers found that non-acoustical factors are also significant, showing that sensitivity can affect sleep disturbance by influencing such factors as sleep quality and the time needed to fall asleep.[11]

In the present study, field studies in communities around railways and roads are introduced and the relationships between the noise levels of railway and road traffic and the corresponding self-reported sleep disturbance levels are established. Sleep disturbance was evaluated through self-assessed surveys from two groups of people exposed to railway or road traffic noise. Six hundred and ten people in 18 sites of railway noise and 550 people in 17 sites of road traffic noise were surveyed using questionnaires. The exposure-response relationships of the two noise sources are compared and the moderating effects of the non-acoustical factors of gender, age and sensitivity, are analyzed. Annoyance in the previous research of CENVR (Center for Environmental Noise and Vibration Research) concerned with the dissimilar European responses are discussed as well.[8,9]

II. MATERIALS AND METHODS

A. Survey design

The field survey described in this paper is the first large-scale noise survey in Korea. It was supported by the Korean Ministry of the Environment as part of "The Eco-technopia 21 Project." For four years beginning in 2004, extensive research on the effects of transportation noise was conducted, with subjective sleep disturbance by nocturnal noise as one of the major subjects. Measurements of night-time transportation noise and assessments of noise-induced sleep disturbance were conducted to evaluate the relationships between long-term noise exposure and the community response and to compare the responses from different noise sources.

The survey was carried out in both the spring and fall of 2004 and 2005 at 18 sites along the Gyungbu and Honam railway lines. All research locations are located in Daejeon and Cheonan, major cities in Korea. For road traffic noise, the survey was carried out in the fall of 2005 and 2006 at 17 sites around the principal roads and the expressways of Seoul, Korea. The surveys were conducted at different times of the year, but the climatic conditions were similar during the survey periods and the survey annoyance questions asked about the previous year. There was little difference among the survey periods (spring and fall of 2004, 2005 and 2006) in Korea regarding the air pressure, air temperature, wind speed, and relative humidity according to the climate information offered by the Korea Meteorological Administration.

Before the site selection, a preliminary survey was conducted concerning the location, weather, topography, background noise, and the circumstances including other noise sources. The sites exposed to significant background noise were excluded, and all extraordinary situations that occurred during the survey were reported by researchers.

Table I shows the information pertaining to the survey sites, including the number of passing vehicles, the composition rates, and the distances between the measurement points and noise sources. The rate of freight trains and heavy vehicles in Table I are the average values of the railway lines and roads (freight trains: 56%, heavy vehicles: 31%) in the respective areas. Traffic conditions of different railways were similar; the standard deviation of the average values of the composition rates for railways was 3.4 while that for roads was 2.9. The measurement points of the survey sites were located between 15 m and 250 m from noise sources. All of the sites were located in residential areas. The residential types in the survey sites were multi-story apartments, which is the most common type of residence in Korea.

B. Noise measurements

Noise measurements were carried out continuously with sound level meters (B&K Types 2238 and 2250 and Larson & Davis 812) for 3 days at each survey site. In the case of railway and road noises, sound levels during weekdays were largely steady, as the operation of railway traffic follows a regular time schedule and because road traffic shows a steady flow on the principal roads. The instruments were in operation from 22:00 p.m. to 07:00 a.m. during the measurement and recorded 1 s LAeq continuously. The outdoor microphones were tripod-mounted at a height of 1.5 m above the ground; they were positioned at least 1 m from any other reflecting surface, in such a way that there were no major influences of the buildings or other acoustical obstacles.

Each microphone was installed on the most exposed façade of the building. When more than one building was selected, they were parallel to the noise sources with the sleeping rooms facing toward the outside roads or railways. It was verified with noise mapping software [CadnaA (DataKustik)] that the differences between the noise levels at different stories in a building or the sound insulation of the noise barriers of different buildings were less than 3 dB at the selected sites.

C. Social survey method

To investigate self-assessed sleep disturbance in populations for transportation noise, a questionnaire survey was given to the residents who lived at the survey sites. A standardized questionnaire developed in previous research was used for this study.[9] The questionnaire consisted of two parts: general questions including demographic information such as age and gender, and questions related to subjective responses to noise.

A question to investigate self-assessed noise sensitivity was 'How much are you sensitive to noise' and the question pertaining to sleep disturbance was 'How much have you been disturbed in your sleep by railway noise (or road traffic noise) at night when you are sleeping in your house over the last 12 months?' Subjects assessed their subjective sleep disturbance from nocturnal noise (or sensitivity to noise) on a scale from 0 to 10. '0' denoted 'not disturbed at all (or not sensitive at all)', and '10' denoted 'extremely disturbed (or extremely sensitive)'. Fields *et al.* reported that a 0–10 numerical scale is likely to be easily understood by people of all countries and cultures who are familiar with currency in a base-10 monetary system.[12] The percentage of the responses ranging from 8 to 10 is termed the percentage of the highly sleep-disturbed population (%HSD). The percentage of responses 6 or higher is termed the percentage of the sleep-disturbed population (%SD).

Twelve hour long survey was done in front of the survey buildings to ask for participations to residents going in and out of the buildings. All respondents reported their addresses to identify their locations within the survey site. The questionnaires were administered in person. The respondents read and completed the paper questionnaire while under the supervision of an interviewer to prevent respondents from reading other questions in advance. The response rate was close to 65%. There were a total of 610 questionnaires analyzed here for railway noise areas and 550 for road traffic noise areas.

Approximately 77% of the subjects were female, with 23% therefore male. They were between 18 and 76 years old. Most of the subjects were middle-aged females (30s–50s). This is most likely related to the fact that they were at home more and had a more favorable attitude regarding joining the survey, despite the fact that there was no pre-explanation or information given before the survey. An additional survey is in progress to obtain a representative sample with regards to both age and gender. Data from the residents who lived in the sites for less than one month were excluded in this study. The mean duration in which the participants lived in both road and railway noise areas was nearly 6 years. The participants' statistics are shown in Table II.

TABLE II. Participants' characteristics: railway and road traffic noise data sets.

		Age group					
Type	Gender	–30	30–40	40–50	50–60	60–	Total (%)
Railway noise	Female	61	230	92	29	56	468 (76.7)
	Male	29	30	31	28	24	142 (23.3)
	Total	90	260	123	57	80	610 (100)
Road traffic noise	Female	85	156	99	56	28	424 (77.1)
	Male	44	11	14	23	34	126 (22.9)
	Total	129	167	113	79	62	550 (100)

III. ANALYSIS AND RESULTS

A. Noise exposure

Subjectively evaluated sleep disturbance due to railway and road traffic noise is related to the equivalent noise level.[13] In this study, $L_{Aeq,22\text{-}07}$ at the most exposed façade of the dwellings is used to describe exposure during the nighttime. The mean values of $L_{Aeq,22\text{-}07}$ at the railway and road traffic noise sites are 58.9 and 58.3 dB(A), and the standard deviations are 6.6 and 6.2, respectively. $L_{Aeq,22\text{-}07}$ of railway noise consists of repetitive single events is calculated from the energy sum of single-event sound exposure levels except background noise and $L_{Aeq,22\text{-}07}$ of road traffic noise is calculated as the energy sum of total sound exposure since road traffic noise was considered as the sum of many repetitive single-event sounds in this research, which there are more than 70 pass-by vehicles per minute in a site with heavy traffic.

The noise levels at night in both the railway and road sites are considerably high. The maximum noise levels of each survey sites are presented in three categories based on $L_{Aeq,22\text{-}07}$ levels in Table III, where $L_{A\,\max}$ is defined as the arithmetic average of the noise level of the highest pass-by measured on each of three consecutive nights. The mean difference between $L_{Aeq,22\text{-}07}$ and $L_{A\,\max}$ for the 18 railway noise survey sites was 17.8 (Std. Deviation=3.6), which is relatively high compared to that of the 17 road traffic noise survey sites (Mean=10.5, Std. Deviation=3.4).

The noise exposures for entire dwellings within a survey site were evaluated by noise mapping software and measured noise levels. The survey participants reported their exact addresses and the position and the direction of their sleeping rooms on the questionnaire, which make it possible to identify their outdoor exposure levels.

B. Factors affecting subjective sleep disturbance response

Railway and road traffic noise can cause different responses in subjective sleep disturbance. The effects of acoustical factors such as the emergence of noise and the peak noise level can cause more intermittent and disturbing responses to railway noise, as shown in previous researches in which the peak noise level was found to be significantly related to subjective sleep disturbance factors such as sleep quality and body movements.[14]

TABLE III. Description of the noise levels in survey sites.

	$L_{Aeq,22\text{-}07}$49–56 dB(A)			$L_{Aeq,22\text{-}07}$56–64 dB(A)			$L_{Aeq,22\text{-}07}$64–74 dB(A)	
Railway	$L_{Aeq,22\text{-}07}$	$L_{A\,max}$		$L_{Aeq,22\text{-}07}$	$L_{A\,max}$		$L_{Aeq,22\text{-}07}$	$L_{A\,max}$
RW 12	55.1	70.6	RW 4	60.9	73.3	RW 1	70.0	90.4
RW 13	51.8	67.1	RW 7	62.8	81.2	RW 2	67.6	86.0
RW 14	51.5	73.7	RW 8	61.8	78.7	RW 3	64.4	86.5
RW 15	50.8	70.9	RW 9	61.9	74.0	RW 5	64.6	80.5
RW 16	49.6	64.9	RW 10	59.8	77.8	RW 6	64.5	86.3
RW 18	47.1	59.2	RW 11	59.2	83.2			
			RW 17	57.5	76.6			
	$L_{Aeq,22\text{-}07}$49–56 dB(A)			$L_{Aeq,22\text{-}07}$56–64 dB(A)			$L_{Aeq,22\text{-}07}$64–74 dB(A)	
Road traffic	$L_{Aeq,22\text{-}07}$	$L_{A\,max}$		$L_{Aeq,22\text{-}07}$	$L_{A\,max}$		$L_{Aeq,22\text{-}07}$	$L_{A\,max}$
RT 1	50.8	60.7	RT 2	59.0	71.5	RT 10	73.2	78.8
RT 6	49.9	62.3	RT 3	62.5	75.2	RT 11	69.5	76.0
RT 7	54.4	67.4	RT 4	61.9	67.6			
RT 8	55.4	62.2	RT 5	56.4	67.4			
RT 15	51.1	65.4	RT 9	58.4	66.5			
RT 17	55.7	67.8	RT 12	58.8	64.7			
			RT 13	56.3	71.0			
			RT 14	61.0	73.7			
			RT 16	56.0	71.4			

It is known that some people are more vulnerable than others to noise owing to related non-acoustical factors that modify noise effects;[15,16] hence, an assessment of the effects of non-acoustical factors as well as acoustical factors is indispensable when studying human responses.

Logistic regression analysis was used to elucidate the effects of non-acoustical factors. By means of logistic regression, an estimator depending on the examined factor (e.g., subjective sleep disturbance) was calculated considering influencing factors (explanatory variables). In total, three explanatory variables that were assumed to influence the result were included in the logistic regression. These variables were "age," "gender" and "sensitivity" which have mostly considered in previous researches.[17] Gender was employed as a dummy value in the logistic regression. The absence of correlation and multicollinearity between explanatory variables is required. In the regression analysis with railway noise data set, there was no multicollinearity at all while a weak correlation only between gender and age was assessed (Pearson's correlation=0.004, $p<0.01$). In case of road traffic noise, unless several variables were correlated (e.g., for gender and age, Pearson's correlation=0.112, $p<0.01$; for gender and sensitivity, Pearson's correlation=−0.092, $p<0.01$), the result of this analysis indicates no multicollinearity between all explanatory variables.

From an analysis with railway noise data set, the effects of "age" and "sensitivity" on sleep disturbance level were proven to be significant. However, for road traffic noise, only "sensitivity" has a significant probability ($p<0.01$). For both railway noise and road traffic noise, sensitivity to noise was a significant factor that influences the subjective sleep disturbance. The results of the analysis are shown in Table IV.

C. Exposure-response relationships for railway and road traffic noise

The logistic regression model was used to estimate the factors which influence the sleep disturbance response and to establish a direct probability model. Logistic regression is a widely used method to predict the dependent variable in epidemiological studies, which it has several advantages of using without an assumption about the variable distribution.[18]

Logistic regression analysis established subjective sleep disturbance response curves from night-time noise. A datapoint contained at least 30 responses, and the corresponding %HSD values are given in Fig. 1 and Fig. 2. The curves here are presented without taking moderation factors into account.

Six hundred and ten railway noise questionnaires were analyzed. The regression model is statistically significant ($P<0.01$). Figure 1 shows the relationship between $L_{Aeq,22\text{-}07}$ and the percentage of a highly sleep-disturbed population (%HSD) for railway noise. The relationship is based on data in the $L_{Aeq,22\text{-}07}$ range from 49 to 70 dB(A) and are expected to give approximate trends for lower exposures and higher exposures. These results have been compared to Miedema

TABLE IV. Evaluation of effects of non-acoustical factors.

		Analysis of logistic regression				
Type	Modifying factors	B	SE	Wald	df	Sig.
Railway noise	Gender	−0.587	0.239	6.051	1	0.014
	Age	−0.008	0.008	1.204	1	0.273
	Sensitivity	0.363	0.042	76.285	1	0.000
Road noise	Gender	−0.046	0.403	0.013	1	0.909
	Age	−0.001	0.011	0.009	1	0.924
	Sensitivity	0.225	0.062	13.062	1	0.000

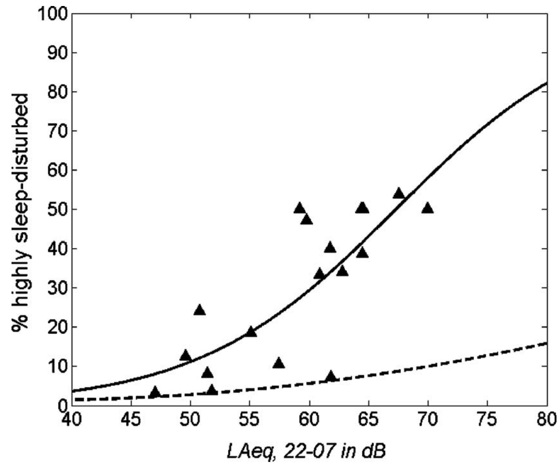

FIG. 1. Percentage of the highly sleep-disturbed population (%HSD) as a function of $L_{Aeq,22\text{-}07}$ in response to railway noise. A solid line and the datapoints in the $L_{Aeq,22\text{-}07}$ range 49–70 dB(A) represent the result of CENVR research, and a dashed line represents the result of European research (Ref. 6).

and Vos's analysis of pooled data from 26 surveys that did include three Japanese surveys, one Turkish survey, but predominately consisted of the 22 surveys from either Europe or English-speaking countries that account for 92% of the respondents in the pooled data.[6] There is a clear difference between the results from this Korean survey and results reported by Miedema and Vos for their predominantly European data. The %HSD curve of CENVR is much higher compared to that in Miedema and Vos[6] the difference between the result in this survey and the average of those 26 surveys might be hypothesized to be due to the following: (1) if Korean houses were closer to the railway lines, then there might be more vibration, (2) background noises may differ, (3) unpleasant feelings or fear resulting from railway noise may differ, and (4) the surroundings of railway areas may cause more subjective sleep disturbances in Korea.

Although some of the subjects lived in less noisy environments, most of the subjects in this research could easily see the trains and they were aware of the railways at all times, as the survey sites consisted of only a few buildings in a small complex and because the differences in noise levels at the sites are mostly due to the sound insulation of the buildings and to the distance of the buildings from the railways. Other psychological and environmental factors which have the potential to induce different responses to noise have not been reported thus far.

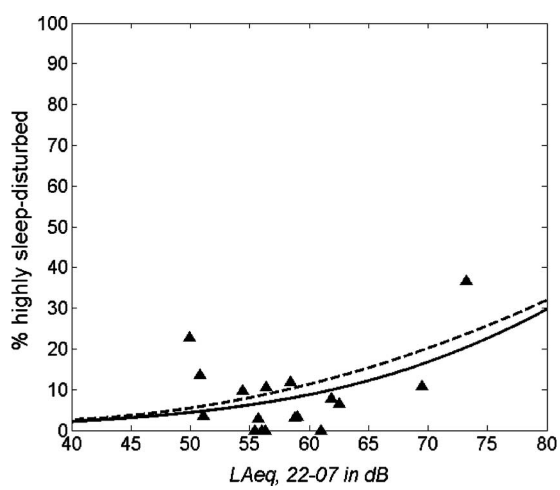

FIG. 2. Percentage of the highly sleep-disturbed population (%HSD) as a function of $L_{Aeq,22\text{-}07}$ in response to road traffic noise. A solid line and the datapoints in the $L_{Aeq,22\text{-}07}$ range 49–73 dB(A) represent the result of CENVR, and a dashed line represents the result of European research (Ref. 6).

For road traffic noise, a logistic regression analysis was also conducted to evaluate the exposure-response relationship. The response curves of subjective sleep disturbance from night-time road traffic noise were established using 550 questionnaires from road traffic noise areas. The regression model is statistically significant ($P < 0.01$). Figure 2 shows the relationship between $L_{Aeq,22\text{-}07}$ and the percentage of the highly sleep-disturbed population (%HSD) for road traffic noise. The relationship is based on data in the $L_{Aeq,22\text{-}07}$ range from 49 to 73 dB(A) and are expected to give approximate trends for lower exposures and higher exposures. Unlike the result of the relationship related to the railway noise, there is some similarity between the road traffic noise-induced subjective sleep disturbance curve in this survey and that for the average of the 26 predominantly European surveys. There is no significant difference between the two sets of results. Previous research found that there is little difference in terms of annoyance toward road noise between Korean and European respondents.[9,19] Given that the environmental factors are similar in the railway and road noise sites of this research, it is reasonable to assume that the different responses toward railway noise in the Korean and European studies derive from different socio-cultural factors.

The following relationships were obtained using the above procedures for the estimation of the percentage of the (highly) sleep-disturbed (%HSD, %SD) on the basis of the $L_{Aeq,22\text{-}07}$ values of the sites:

Railway noise,

$$\%\mathrm{HSD} = 100/[1 + \exp(-0.120 \times L_{Aeq,22\text{-}07} + 8.081)], \quad (1)$$

$$\%\mathrm{SD} = 100/[1 + \exp(-0.139 \times L_{Aeq,22\text{-}07} + 8.832)]. \quad (2)$$

Road traffic noise,

$$\%\mathrm{HSD} = 100/[1 + \exp(-0.074 \times L_{Aeq,22\text{-}07} + 6.785)], \quad (3)$$

$$\%\mathrm{SD} = 100/[1 + \exp(-0.080 \times L_{Aeq,22\text{-}07} + 6.379)]. \quad (4)$$

This study shows that the difference between %HSD and %SD values at the same noise level varies depending on the noise source. In the case of road traffic noise, the difference between %HSD and %SD values is greater than it is with railway noise. This is demonstrated in Fig. 3 with the superposition of the %HSD and %SD curves of road and railway noise. From previous European surveys, railway noise is perceived to be less annoying than other transportation noise. However, Koreans consider railway noise to be very annoying.[19] In fact, this negative attitude toward railway noise is much higher compared to European countries. It

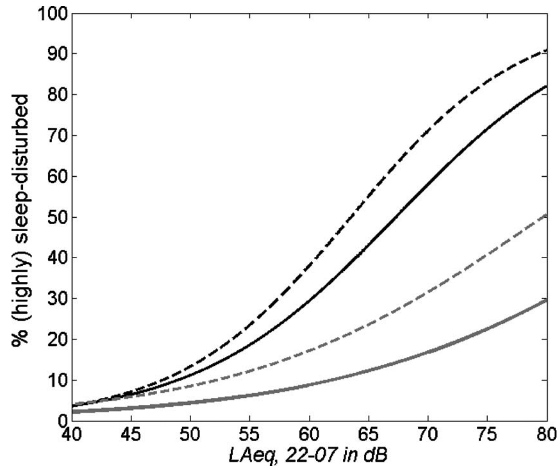

FIG. 3. Comparison of %HSD and %SD curves of railway and road traffic noise. Upper black lines represent the sleep disturbance response caused by railway noise and gray lines represent that caused by road traffic noise; a solid line is a %HSD curve and a dashed line is a %SD curve.

can be considered that there are some similarities between the annoyance response and subjective sleep disturbance.

The analysis of the railway noise data set showed that the subjects' gender had a significant influence on subjective sleep disturbance, while the difference was quite small. On the other hand, gender did not have any statistical significance in the case of road traffic noise. This point observation leaves room for further discussion about cases in which the gender and age ratios of the participants vary.

The difference in subjective sleep disturbance responses, in terms of subjects' sensitivity, was shown to be statistically significant in the analysis of both the railway and the road traffic noise data sets. Figure 4 illustrates the effect of noise sensitivity, showing that the difference in %HSD values varies, depending on subjects' sensitivity. The self-assessment levels, from 8 to 10, of sensitivity to noise were considered the "high sensitivity group." Those from 0 to 2 were considered the "low sensitivity group." Respondents who reported a high score for noise sensitivity were expected to be more sleep-disturbed at the same exposure level. CENVR-%HSD curves presented in all the figures are established with data in the $L_{Aeq,22\text{-}07}$ range 49–70 dB(A) for railway noise and $L_{Aeq,22\text{-}07}$ range 49–73 dB(A) for road traffic noise.

IV. CONCLUDING REMARKS

In this study, a large field survey and statistical analysis were carried out to evaluate exposure-response relationships with subjective sleep disturbance from railway and road traffic noise. Relationships between $L_{Aeq,22\text{-}07}$ and the percentage of the highly sleep-disturbed population (%HSD) were established, and it was found that there was more subjective sleep disturbance from railway noise than from road traffic noise. We found a significant increase in the difference in the %HSD value in railway and road traffic responses as the noise level increased. This result implies that sleep is more affected by railway noise than by road traffic noise and that people are more vulnerable to railway noise.

For different types of noise exposure, the response to noise exposure depends on acoustical factors. Railway noise which has more intermittent occurrences and higher peak levels may cause more subjective sleep disturbance than road traffic noise. Furthermore, the rate of freight trains or heavy vehicles may cause the responses to differ. Fields and Walker compared annoyance levels from freight trains and passenger trains after the effects of differing noise levels were removed. They concluded that some analysis approaches showed that the annoyance level is increased considerably by more freight traffic only in the event of a change from a small to a moderate proportion of freight trains.[20] However, de Jong and Miedema examined additional surveys with different analysis techniques and found that after the effects of differing noise levels are removed, there are no differences in dose-response relationships between different proportions for freight trains.[21] The effects of the rate of freight trains or heavy vehicles remain inconclusive and show insufficient scientific evidence.

Since many researchers have paid attention to the effects of attitudinal factors on the subjective response to noise, the noise sensitivity of subjects, which is one of the most significant factors, was analyzed in this article. The sensitivity of the participants was shown to be a significant modifying factor, as it pertains to subjective sleep disturbance. In this study, the effect of the age on subjective sleep disturbance did not show any statistical significance, and only in the case of railway noise gender was a significant factor influencing sleep disturbance. Other demographic factors were excluded from the analysis because they were considered less impor-

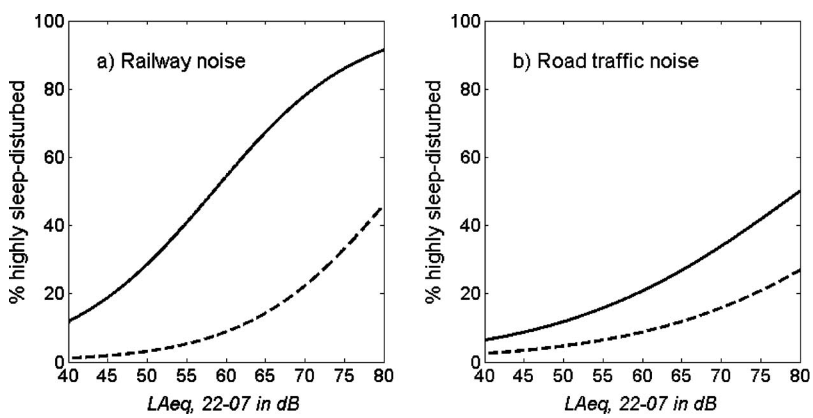

FIG. 4. %HSD curves in response to the sensitiveness of subjects. Solid lines represent "high sensitivity group" (the responses of 8 to 10 in self-assessed sensitivity to noise) and the dashed lines represent "low sensitivity group" (The responses of 0 to 2).

tant, being related to the subjective response to noise.[17] There is room for further discussion regarding the moderating effects of these demographic factors.

From a comparison between analyses of multi-survey, primarily European, pooled data sets and this Korean survey, the subjective sleep disturbance with railway noise appears to be higher in Korea, whereas there appears to be no significant difference in road traffic noise-induced subjective sleep disturbance despite the slight increase in recent result.[6] This may be due to the different attitudes between Koreans and Europeans regarding noise sources. Fields *et al.* explained the reason for different annoyance responses to different noise sources as stemming from human attitudes as well as the characteristics of the noise.[22] The result corresponds well to the previous CENVR result, in which the annoyance response to railway noise in Korea was shown to be significantly higher than the response from road traffic noise, contrary to the result of the European surveys but in agreement with that of Japanese surveys.[8,9] Accordingly, several similarities are apparent between the annoyance response and subjective sleep disturbance.

The comparison of the responses between railway and road traffic noise and the fact that Koreans are disturbed more in their sleep by railway noise compared to Europeans are important results. This result can lead to a reconsideration concerning the ‘railway bonus’, which limits the noise for railways, possibly making it less stringent than for roads in some European countries. This contention is based on the results from European researches in which railway noise caused less annoyance than road traffic noise. However, several recent studies in Korea and Japan have reported contradictory results, in which the annoyance level for railways was higher than that for roads. Previous laboratory experiments in Korea have also shown that road traffic noise causes less sleep disturbance than railway noise, with more body movement during sleep according to actimetry signals.[23] Further extensive research should be directed at determining the different responses in subjective sleep disturbance between the different studies and studying the modifying factors on subjective sleep disturbance.

ACKNOWLEDGMENTS

This work was supported by the Core Environmental Technology Development Project for Next Generation in Korea Institute of Environmental Science and Technology, and Engineering Research Institute of Seoul National University. This paper covers all methodological information on field survey by following “Journal Reporting Guidelines” which were previously suggested by Fields *et al.*,[24] and newly updated in 2009 by the Community Response Team of ICBEN (International Commission on the Biological Effects of Noise) which is currently chaired by Takashi Yano and Soogab Lee.

[1]B. Griefahn, P. Mehnert, U. Moehler, A. Schuemer-Kohrs, and R. Schuemer, “Design of a field study on the effects of railway noise and road traffic noise, in Proceedings of Inter-Noise 96 (1996).

[2]B. Griefahn, “Long-term exposure to noise. Aspects of adaptation, habituation and compensation,” Waking Sleeping **1**, 383–386 (1977).

[3]B. Griefahn, C. Deppe, P. Mehnert, R. Moog, U. Mohler, and A. Schumer-Kohrs, “Intermittent versus continuous noises. Their influence on sleep latency and motility during the night,” in Proceedings of Inter-Noise 98 (1998).

[4]T. J. Schultz, “Synthesis of social surveys on noise annoyance,” J. Acoust. Soc. Am. **64**, 377–405 (1978).

[5]L. S. Finegold, C. S. Harris, and H. E. von Gierke, “Community annoyance and sleep disturbance: Updated criteria for assessing the impacts of general transportation noise on people,” Noise Control Eng. J. **42**, 25–30 (1994).

[6]H. M. E. Miedema and H. Vos, “Associations between self-reported sleep disturbance and environmental noise based on reanalyses of pooled data from 24 studies,” Behav. Sleep Med. **5**, 1–20 (2007).

[7]H. M. E. Miedema, “Exposure-response relationships for environmental noise,” in Proceedings of Inter-Noise 07 (2007).

[8]C. Lim, J. Kim, J. Hong, and S. Lee, “The relationship between railway noise and community annoyance in Korea,” J. Acoust. Soc. Am. **120**, 2037–2042 (2006).

[9]CENVR, *Assessment Methods of Adverse Effects on Human of Environmental Noise and Vibration* (Ministry of Environment, Korea, 2007).

[10]T. Yano, T. Yamashita, and K. Izumi, “Comparison of community annoyance from railway noise by different category scales,” J. Sound Vib. **205**, 505–511 (1997).

[11]E. Öhström and M. Björkman, “Effects of noise-disturbed sleep: A laboratory study on habituation and subjective noise sensitivity,” J. Sound Vib. **122**, 277–290 (1988).

[12]J. M. Fields, R. G. de Jong, T. Gjestland, I. H. Flindell, R. F. S. Job, S. Kurra, P. Lercher, M. Vallet, and T. Yano, “Standardized general-purpose noise reaction questions for community noise surveys: Research and a recommendation,” J. Sound Vib. **242**, 641–679 (2001).

[13]B. Griefahn, A. Marks, and S. Robens, “Noise emitted from road, rail and air traffic and their effects on sleep,” J. Sound Vib. **295**, 129–140 (2006).

[14]E. Öhström and R. Rylander, “Sleep disturbance by road traffic noise. A laboratory study on number of noise events,” J. Sound Vib. **143**, 93–101 (1990).

[15]H. M. E. Miedema, W. Passchier-Vermeer, and H. Vos, *Elements for a Position Paper on Night-time Transportation Noise and Sleep Disturbance* (TNO Inro, Delft, The Netherlands, 2003).

[16]B. Berglund, T. Kilman, W. Kropp, and E. Öhström, Soundscape Support to Health (Chalmers, MISTRA, 2004).

[17]H. M. E. Miedema and H. Vos, “Demographic and attitudinal factors that modify annoyance from transportation noise,” J. Acoust. Soc. Am. **105**, 3336–3344 (1999).

[18]S. M. Hailpern and P. F. Visintainer, “Odds ratios and logistic regression: Further examples of their use and interpretation,” The Stata Journal **3**(3), 213–225 (2003).

[19]S. Lee, J. Hong, J. Kim, C. Lim, and K. Kim, “Exposure-response relationships on community annoyance to transportation noise,” in Proceedings of ICBEN 2008 (2008).

[20]J. Fields and J. Walker, *Reactions to Railway Noise: A Survey Near Railway Lines in Great Britain* (University of Southampton Institute of Sound and Vibration Research, Southampton, 1980).

[21]R. G. de Jong and H. M. E. Miedema, “Is freight traffic noise more annoying than passenger traffic noise?,” J. Sound Vib. **193**, 35–38 (1996).

[22]J. M. Fields and J. G. Walker, “Comparing the relationships between noise level and annoyance in different surveys: A railway noise vs. aircraft and road traffic comparison,” J. Sound Vib. **81**, 51–80 (1982).

[23]J. Hong, J. Kim, C. Lim, K. Kim, and S. Lee, “Assessment of sleep disturbance on night-time railway noise from the field survey,” in Proceedings of Inter-Noise 06 (2006).

[24]J. M. Fields, R. de Jong, A. L. Brown, I. H. Flindell, T. Gjestland, R. F. S. Job, S. Kurra, P. Lercher, A. Schuemer-Kohrs, M. Vallet, and T. Yano, “Guidelines for reporting core information from community noise reaction surveys,” J. Sound Vib. **206**, 685–695 (1997).