

INTER-NOISE 2006

3-6 DECEMBER 2006
HONOLULU, HAWAII, USA

Assessment of sleep disturbance on night-time railway noise from the field survey

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ABSTRACT

Sleep disturbance has been recommended as one of the environmental health indicators by the World Health Organization. In Korea railway noise happens frequently even at night in residential areas unlikely that aircraft rarely operate at night. But there are no criterions or methods for assessing sleep disturbance in Korea. Therefore, we have conducted the present research to investigate effects of night-time railway noise on sleep. Field survey had been carried out twice times to evaluate the instantaneous effects and the long-term effects of noise on sleep. In the first study to assess the instantaneous effects, noise level and the acceleration signal of body movement of the subject were measured in 12 survey points. Body movement was evaluated by %motility using actiwatch. As the second study for assessing the long-term effects, the questionnaire survey had been carried out. Study 2 was performed in 18 sites along Gyungbu and Honam railway lines. We have established two kinds of sleep disturbance curves from analysis of the instantaneous effects and the long-term effects and it has been shown that noise-induced sleep disturbance responses of Korean are different from other countries'. And the results of this research are expected to use for policy making and decision activities.

1 INTRODUCTION

Most of the complaints of populations living where transportation noise is serious mainly refer to annoyance and sleep disturbance. Many social surveys have been conducted throughout the world, and the previous work in this laboratory has established the relationship between noise exposure and annoyance in Korea [1,2]. Recently, many studies assessed noise-induced sleep disturbance, and mainly focused on sleep disturbance due to night-time aircraft noise. There are many methods used to investigate the effects of noise on sleep. Lukas et al. (1971) conducted the laboratory experiment to investigate behavioral awakening and arousal by EEG recording [3]. Finegold et al. (1994) have proposed the relationship between percentage of awakening and noise level based on meta-analysis of eight field studies [4]. Miedema et al. (2002, 2003) used questionnaire in order to find the relationships between noise levels and their corresponding subjective and objective responses [5,6].

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Even if noise-induced sleep disturbance lately becomes a subject of special interest and public interest in this is rising, techniques or methods for assessing sleep disturbance have not been reported yet. The present research has been conducted to establish two kinds of sleep disturbance curves from analysis of the instantaneous effects and the long-term effects with respect to noise metrics. We obtained an interesting result that noise-induced sleep disturbance responses of Korean are different from other countries'. And further work for assessing noise-induced sleep disturbance in various methods is still continuing.

2 METHOD

2.1 Overall Survey Design

Field survey had been carried out to evaluate the effects of night-time railway noise on sleep. Study 1 was aimed to assess the instantaneous effects and noise measurements were performed near Gyungbu railway lines. From 22-7h indoor noise monitors in the bedroom of each subject and outdoor noise monitors(B&K type 2238 and Larson & Davis 812) were simultaneously measured and time-synchronized each other. Most of noise events of regularly operated trains were identified by time table of railway service acquired from Korea Railroad Corporation. The instantaneous sleep disturbance from railway noise events was investigated by using actiwatch (Mini Mitter type AW-Score) which measures the acceleration of body movement of subjects in sleep.

For assessing the long-term effects, study 2 was performed in 18 sites along Gyungbu and Honam railway lines. Measuring time and instruments for noise measurement were the same as study 1 and outdoor noise monitors were only operated. The criteria for the site selection was that they have high volumes of train operations, the two lines are responsible for above 60% of passenger transport and freight in the whole railway industry. Table 1 shows distances from railways to measurement points in study 2. The average distance was 90m, and about 80% of sites were located within 100m from railway. Sleep disturbance was investigated by means of a questionnaire. The questionnaire survey was performed to subjects living within 50meters from noise measurement point.

Table 1 : Distance from railway to survey points of study 2

Distance (m)	d<20	20<d<40	40<d<100	100<d<200	d>200
Number of sites	3	4	7	2	2
Percentile (%)	16.7	22.2	38.9	11.1	11.1

2.2 Study 1 : Instantaneous Effect of Railway Noise on Sleep

-Noise metrics

The instantaneous effects of noise on sleep are related to metrics of individual noise events such as the maximum sound level(LA_{max}) or the sound exposure level(SEL). SEL is defined to be the integration of the sound energy related to a single event (ISO 1996-1:2002). In practice, LA_{max} is easier to measure than SEL and to exclude low levels of background noise, relations between LA_{max} and SEL have been used in this study. These relations depend on the time pattern of the noise event. Since railway noise event appears the triangular time pattern, in the

relation of that case, SEL is taken to be the sound energy in the period in which the level of the event is above $LA_{max} - 10$. SEL can be easily calculated by following relation based on LA_{max} and duration [7].

$$SEL = LA_{max} + 10 \log D_{10}/D_{ref} - 3.7 \text{ (triangular time pattern)} \quad (1)$$

D_{10} is 10 dB down duration from maximum sound level and D_{ref} is the reference duration of 1 s.

The indoor and outdoor levels were measured with sound level meters simultaneously. The measurement of the outdoor noise was used for identifying railway noise events from the indoor measurement, which is relatively low to distinguish with the background noise. Due to low correlation between outdoor noise levels and sleep disturbance, indoor noise levels were only used for evaluation of sleep disturbance [8].

In study 1, noise measurements were performed from 22-07h in 12 survey points located near Gyungbu railway lines during a week. Table 2 shows the statistical information of indoor and outdoor LA_{eq} , number of events and event duration of entire night's noise exposure on survey points. Number of total events which has been used to analysis in this study is 1708. The mean values of indoor LA_{max} and SEL are 54.8dBA and 64.1dBA respectively, the standard deviations are 8.6 and 9.0. Correlation coefficients(R) of LA_{max} and SEL are statistically significant. And the mean value of total event duration is 24.5s.

Table 2 : Summary of measurements of entire night's noise exposure on survey points of study 1

	Noise metrics			
	Outdoor LAeq	Indoor LAeq	No. of events	Total duration
mean	58.8dB	48.4dB	75.2	24.5s
SD	6.2	5.2	2.9	10.3

- Body movement

To investigate whether night-time railway noise events affect on sleep disturbance, body movement of subject had been measured using actiwatch. 12 participants wore actiwatch on their wrist for 24 hours during a week. Generally it is recommended to wear an actiwatch on subject's nondominant wrist. Jovanovic found that the nondominant hand was two times more active than the dominant one during sleep, independent of the phase of the REM-NREM cycle [9]. Among 12 subjects, consisted of 6 male subjects and 6 female subjects, number of 30~40s are 7, over 50 s are 4, and twenties is only one.

The actiwatch uses an omnidirectional accelerometer to sample acceleration 32 times per second with a signal threshold of 0.05g. This information is digitally integrated to obtain counts of total activity for 15-second epochs. Sleep/Wake algorithm which is applied to actiwatch software provides about 95% correlations with PSG in case of healthy older adults [10]. This algorithm marks 'wake' if total activity score in each epoch is higher than threshold sensitivity value of activity (40 in case of medium) [11]. In this study, activity value of being over the

threshold sensitivity was regarded as the effective body movement arose from noise-induced sleep disturbance.

2.3 Study 2 : Long-term Effect of Railway Noise on Sleep

- Noise metrics

Noise measurement was carried out using outdoor noise monitors, which time and frequency weightings were set to be ‘fast’ and ‘A’, and time history of noise level was logged in every 5 sec. L_{night} has been used as a predictor of long-term effects of night-time noise exposure, such as self-reported sleep disturbance. L_{night} is equivalent sound pressure level during night-time (22-7h), and it includes the influence of individual noise events to the overall noise exposure. When the night-time noise is caused by individual noise events, such as railway noise, L_{night} can be taken to be the sum of the individual sound exposure levels caused by noise events divided by the duration of the night-time period.

- Self-reported sleep disturbance

Self-reported sleep disturbance has been investigated by using a questionnaire. This questionnaire survey was carried out to residents living within about 50 meters from noise measurement point. The question for assessment of sleep disturbance is ‘How much have you been disturbed your sleep from night-time railway noise?’. Respondents could answer on a scale from 0 to 10. ‘0’ means ‘not disturbed’ and ‘10’ means ‘extremely disturbed’. If the percentage of the responses exceeding a cut-off at 72 on the scale from 0 to 100, then it is called percentage of highly sleep disturbed population (%HSD). With a cut-off at 50 it is the percentage of sleep disturbed population (%SD), and with a cut-off at 28 it is the percentage of a little sleep disturbed population (%LSD) [12]. These definitions are similar to the assessment of annoyance.

The survey was performed to randomly passing-by people in the survey area and the response rate of people who answer the question, counting some respondents who were asked to participate 2-3 times by interviewers, was about 65%. The total number of respondents was 613. About 77% of the respondents were female and 23% were male. An age structure of respondents can be distributed like younger than 20 years old (4%), 20-40 (37%), 40-60 (38%) and older than 60 years old (21%).

3 RESULT

3.1 Study 1 : Motility Response Caused by Instantaneous Railway Noise Events

Table 2: Information of LA_{max} and SEL of 1708 noise events

range	Noise metrics	
	LA_{max}	SEL
<40	92	8
40-50	392	104
50-60	755	419
60-70	391	731
70-80	76	382
>80	2	64

Indoor LA_{max} and SEL of each noise event measured in subject's bedroom and their corresponding number of events is given in table 2. Since all subjects are living within 60 m from railway, noise exposure is quite high in spite of being measured indoors with windows closed.

If activity score in each epoch is higher than the threshold sensitivity value which is 40 in this study, then we determined that $m=1$, otherwise, $m=0$. Activity value of being over the threshold sensitivity was regarded as the effective body movement arose from noise-induced sleep disturbance. %motility was determined as a probability of $m=1$ within 7 epochs (105 s) including a railway noise event [13]. In study 1, the probability of motility has been used as effect variable for assessing the instantaneous effects from railway noise events.

To match on a time basis the actiwatch recordings to the occurrences of railway noise events, the clock time of indoor LA_{max} was compared with the clock time of actiwatch data. And we decided that the epoch at which LA_{max} of noise events occurs is e6, so an approximate range of analysis has been defined as 20 epochs (300s) including e6, 5 epochs before e6 and 14 epochs after e6. It is long enough that the response delay time of body movement of subject being considered. Since the body movement could be occur before and after as well as at the moment when noise happens, a unit for analysis has to be a longer time than the exact duration of noise event. The criteria for the effective range is that probability of $m=1$ of each epochs in 20 epochs with railway noise events should be higher than mean value of probability of $m=1$ (0.06) for epochs without noise events. 7 epochs (105sec, e4-e10) has been determined as an effective range of analysis in 20 epochs. This result can be seen in figure 1 and very similar to Miedema *et al.*'s.

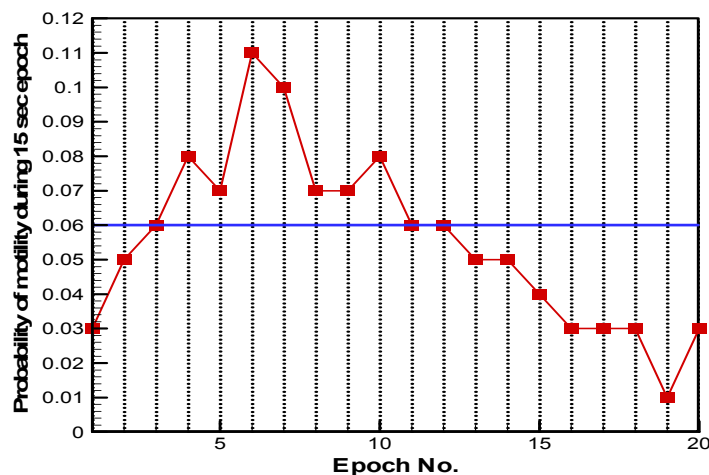


Figure 1: Probability of $m=1$ for 20 epochs with railway noise events (red line and rectangular symbols) and mean value of probability of $m=1$ for epochs without railway noise events (blue line)

Figure 2 shows %motility with respect to LA_{max} and SEL, and the relations between %motility and both noise metrics exhibit a tendency to increase. Corresponding value of %motility with 31dBA which is the lowest LA_{max} of measurement is 1.8%, and 20.6% with the highest 94dBA. For 36-94dBA of SEL have 1.5-22% of %motility. Miedema *et al.* consider

the expected value of probability of motility as probability of motility with noise event subtracted by probability of motility without noise event. In order to compare with the result of study 1, functional relation between noise level and motility was modified and the result of comparison for only SEL from 20-80dBA can be seen from figure 3. Threshold level inducing motility is 38dBA in model proposed by Miedema *et al.* Otherwise, threshold level of Korean model is lower than Miedema *et al.*'s although the model of Miedema *et al.* has been obtained by research of aircraft noise-induced sleep disturbance.

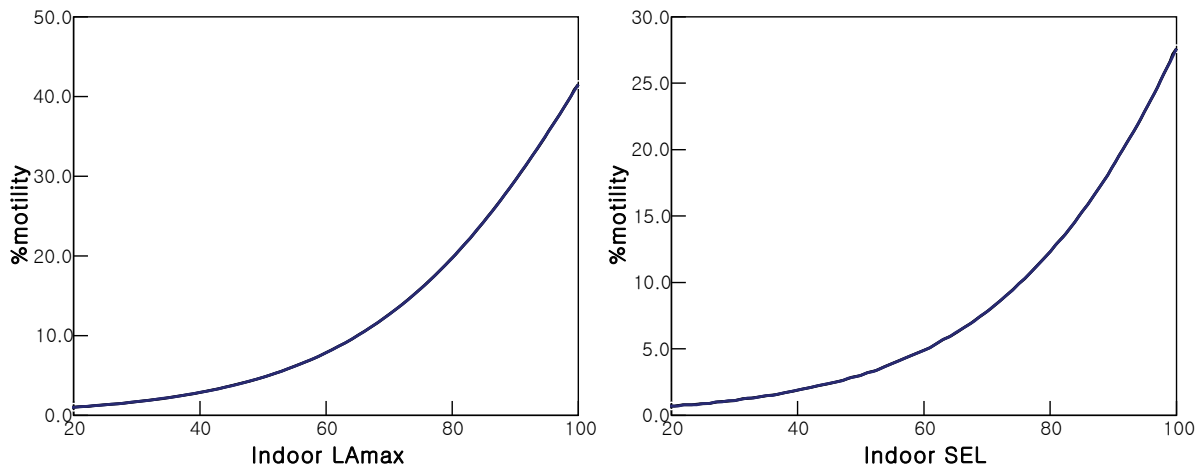


Figure 2: %motility during 7epochs in which noise exposure occurs, as functions of LA_{max} and SEL

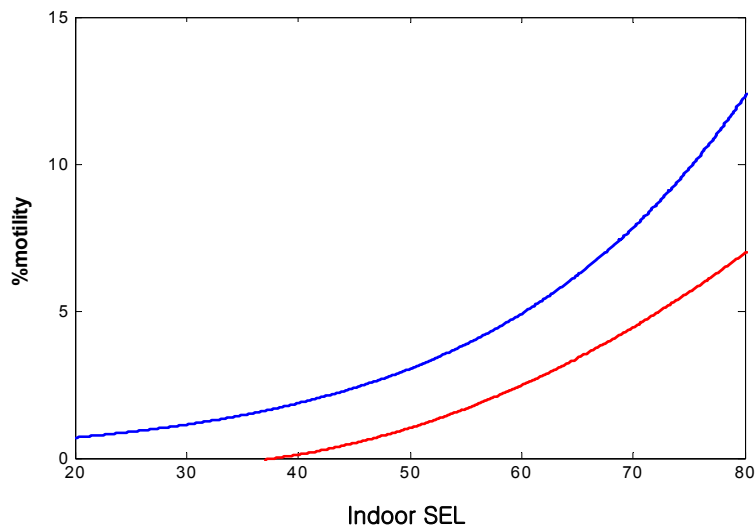


Figure 3: Comparison of the relationship between indoor sound exposure level and probability of motility (blue line is the modified result of Korean research on railway noise and red line is the result of Miedema *et al.*'s research on aircraft noise)

3.2 Study 2 : Self reported sleep disturbance (%HSD) as long-term effect from railway noise

Logistic regression analysis has been carried out by using data from the field survey in 18 sites around railway. Regression model is statistically significant. From figure 4, data points and

the regression relation between equivalent sound level during night-time and percentage of highly sleep disturbed population (%HSD) can be seen. %HSD increased with increasing L_{night} and from 55dBA, the slope of the relation shows a steeper incline. In case of $L_{night} < 55\text{dBA}$, 10 increase in the noise level leads to less than 10 increase of %HSD, but if $L_{night} > 55\text{dBA}$, 10 increase in the noise level leads to more than 10 increase of %HSD.

Subjective response of sleep disturbance from study 2 can be assumed to be considerably high. Fig. 5 compares %HSD model of Korean with model of Miedema *et al.* It is found that Korean subjective response to railway noise is different from European response, and this is in good agreement with the result of study 1. Besides this result corresponds well with the result of previous research in this laboratory, which annoyance response from railway noise in Korea is more negative than European's. It can be generally considered that Korean is more sensitive than European.

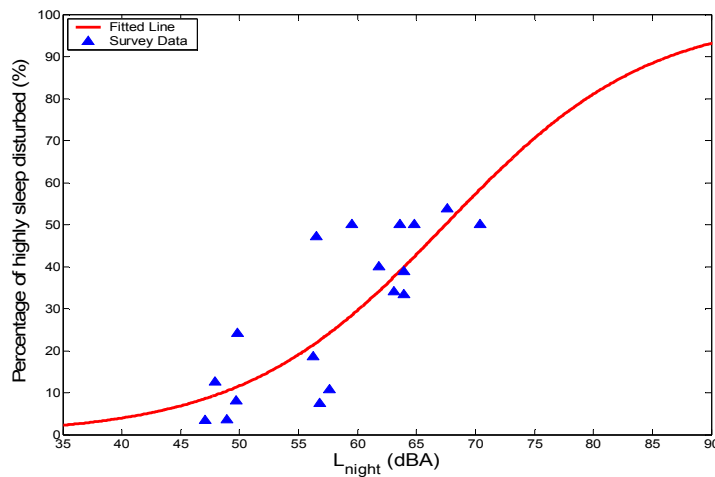


Figure 4 : Data points from the field survey and regression model of %HSD as a function of L_{night}

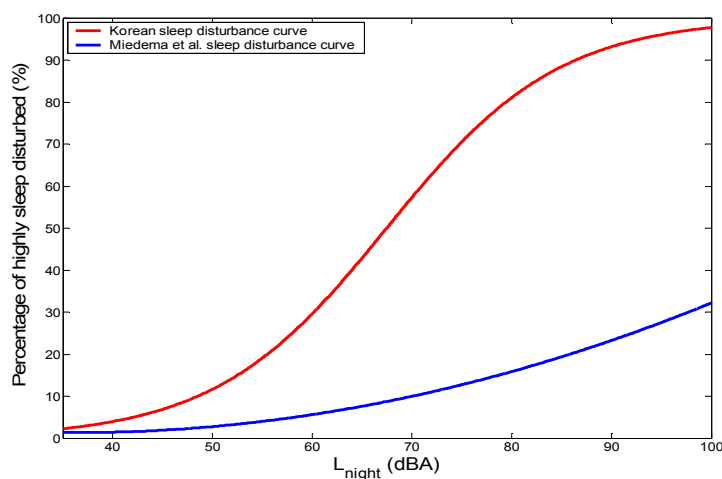


Figure 5 : Comparison of the relationship between L_{night} and %HSD in Korea with the result of other country (Miedema et al. 2002)

4 CONCLUSION

In this research, we have aimed to evaluate the railway noise-induced sleep disturbance by objective and subjective methods. Instantaneous effects of night-time noise have been objectively assessed from the relations between noise metrics and %motility in study 1. Long-term sleep disturbance could be assessed from subjective responses of participants by using the questionnaire survey in study 2.

In study 1, LA_{max} and SEL have been used by noise metrics of instantaneous railway noise events and SEL has been obtained by an approximate relation based on LA_{max} and duration. For assessing body movement of subject, %motility has been measured with actiwatch. %motility could be defined as a probability of occurrence of subject's body movement in sleep. The effective time period for calculating %motility has been determined as 7 epochs (105sec). The result of study 1 shows a tendency to increase of %motility with increasing noise level. And the threshold level inducing motility is lower than Miedema *et al.*'s which surveyed on aircraft noise-induced sleep disturbance.

From the study 2, the assessment of long-term sleep disturbance from railway noise was carried out. The relation between L_{night} and %HSD has been established by logistic regression analysis. %HSD has been recommended as a descriptor of sleep disturbance and the numerical scale of 0 to 10 was used for assessing subjective response. If the percentage of the responses exceeding a cut-off at 72 from 0 to 100, then it is called percentage of highly sleep disturbed population (%HSD). It is found that highly sleep disturbed population increases steeply from L_{night} over 55dBA. It shows similar result with Miedema *et al.*'s. But from the result, it could be assumed that Korean subjective response to night-time railway noise is more sensitive and more negative than European response. And this is in good agreement with the result of study 1 as well as the result of previous research about annoyance response from railway noise. The cause of being more sleep disturbed is considered as the negative impression of Korean to railway noise under the facts that the railways of Korea are very close to houses and it operates frequently at night with loud noise and vibration. And the cultural and social difference between Korean and European could affect on the different subjective responses to night-time noise.

This research is the first trial to evaluate sleep disturbance from night-time railway noise by objective and subjective methods in Korea and the consequent relationships from study 1 and study 2 are expected to use for policy making and decision activities. There remain some variables for assessing sleep disturbance such as, sleep efficiency, sleep quality, health effects, etc. and these will be the subject for a future study.

5 ACKNOWLEDGEMENTS

The present research was funded by Core Environmental Technology Development Project in Korea Institute of Environmental Science and Technology.

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