ENVIRONMENTAL NOISE CONTROL
The 2005 Congress and Exposition on Noise Control Engineering
07-10 August 2005 - Rio de Janeiro - Brazil

Assessment of binaural effects on instantaneous noise annoyance estimation

Jaehwan Kim[a], Changwoo Lim[b], Jiyoung Hong[c], Wontae Jung[d], Soogab Lee[e]

[a,b,c,d]Center for Environmental Noise and Vibration Research, Rm205 Bldg44, Seoul National University, Seoul 151-744, South Korea
[e]School of Mechanical and Aerospace Engineering, Rm1303 Bldg301, Seoul National University, Seoul 151-744, South Korea

[a]kjh03@snu.ac.kr; [b]glider20@snu.ac.kr; [c]hongjy@snu.ac.kr;
[d]wontae@snu.ac.kr; [e]solee@plaza.snu.ac.kr

Abstract Human beings fundamentally hear sound through both ears, referred as binaural hearing. Most indices of transportation noise for measuring subjective responses such as an annoyance are, however, based on measurement using a microphone. Binaural signal, measured by 'head and torso simulator', is different from monaural signal, measured by a microphone, because it includes more information of physical phenomena like acoustical reflection and diffraction. Consequently, subjective responses to monaural and binaural signals would be discriminated. In order to identify this fact, events of transportation were measured using torso simulator and a microphone at the same site and time. Stimuli which were obtained through signal processing of measured noise events have been presented to subjects in simulated environment. This paper shows their difference through laboratory experiments.

1. INTRODUCTION

Environmental noises, such as transportation noise, recreational noise, industrial noise and community noise is recognized as environmental pollutions. Noise assessment and regulation is having been done in many countries. Physical quantities of environmental noise assessment are acquired through measuring by a microphone. But, human beings' hearing is physiologically two channel input system and hearing sound includes physical phenomena in pinna, head and body [1~2]. Thus, noise level as well as frequency characteristics of ears are discriminated from those of signals measured by a microphone. In this study, transportation noise events were measured at the same time using both microphone and torso simulator in order to know binaural effects on subjective responses. And the stimuli for subjective tests were made on the basis of each measured signal. Signals measured by a microphone were reproduced monaurally and signals measured by a torso simulator were reproduced binaurally. Therefore, the former were named as monaural signals and the latter were named as binaural signals in this paper only. Amplitude and spectrum for subjective test were carefully calibrated to minimize the difference between original and processed sound. In this laboratory study, subjective response is represented as an annoyance scale which mainly used in dose-response relationships from socio-acoustical study, or field study [3~6]. Subjects are instructed to mark annoyance scale by themselves after the exposure of transportation noise event like several precedent researches [7~10].

Note that A-weighted sound exposure level, denoted by L_{AE}, of monaural sound was only used as a noise exposure indicator. Provided that physical quantity exposed at the same location and time had difference, it would not proper that only L_{AE} of monaural sound was used as a noise exposure indicator in both cases. Ambiguity of binaural noise level caused by inconsistency between left and right ear is one reason for choosing L_{AE} of monaural sound as noise exposure indicator. And it is another reason that relative position between a microphone and a torso simulator was almost same and measurement was conducted at the same time. This paper would propose a necessity of reflection of binaural effects on transportation noises in instantaneous annoyance through comparison of response between monaural and binaural hearing.

2. MEASUREMENT AND STIMULUS

2.1 Noise measurements

A microphone (B&K 4190) and 'head and torso simulator' (B&K 4100) were placed 1.7m above the ground. And both were placed about 15m away from the edge of road and railway and were placed about 100m away from a takeoff and touchdown point for aircraft. These were directly connected to portable pulse (B&K 3560C) for real-time monitoring and spectral analysis. Except for road traffic noise, noise was recorded as a single event considering their intermittent passing pattern. Sampling rate is set to 65536 Hz with 16 bit quantization. Measurement were performed in open environment and other measurement conditions have been conformed to the description of ISO1996-1, 1996-2 [11~12].

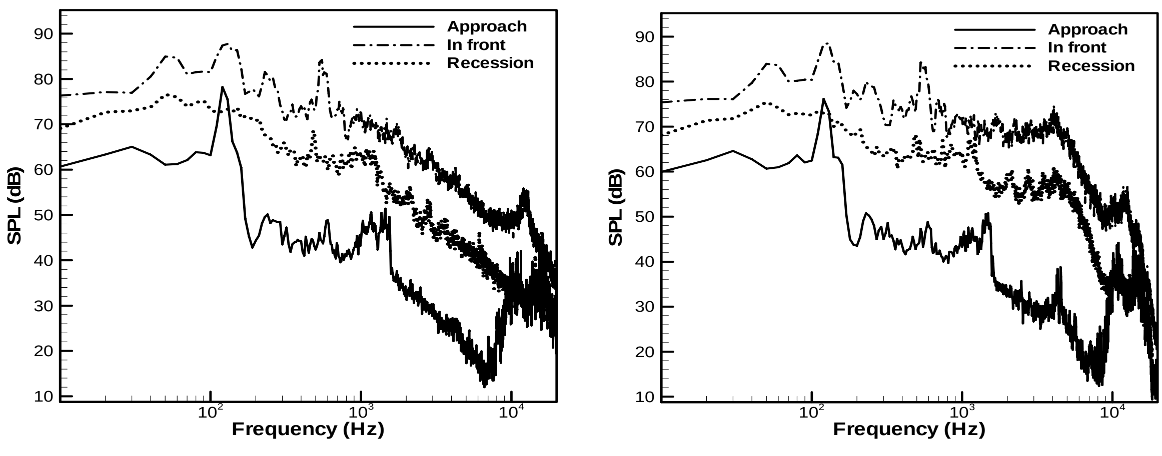

Figure 1: Spectrum of monaural (left fig.) and binaural (right fig.) signal of railway noise. Monaural and binaural recording was done at the same time. Solid line represents approaching of railway vehicle to measurement devices and dash dotted line represents that railway vehicle is passing by in front of measurement devices and dotted line represent recession of railway vehicle after measurement devices.

Figure 1 is frequency characteristics of railway noise measured by a microphone (left fig.) and 'head and torso simulator' (right fig.). From *figure 1*, noise level of 'head and torso simulator' is higher than that of a microphone in approximately from 2 kHz to 5 kHz. This reflects acoustical features by head and pinna. The other noise sources also had similar frequency characteristics.

2.2 Constitution of stimuli

Stimuli based on measured signals for laboratory experiment were composed of 6 test sets. Samples of three noise sources were arranged randomly and silence between each noise event was lasted at least 10 seconds in every test set for subjects not to be influenced from prior noise events during. Also, fade-in and fade-out effects were added in the wave files of noise events artificially on purpose of elimination of discontinuous sound caused by level difference between artificial null sound and ambient noise of the location where transportation noises had been recorded. Equal fraction of three noise events, which were aircraft noise, railway noise and road traffic noise, was assigned to stimuli. Both commercial and military aircraft events were included in aircraft noise events.

3. LABORATORY EXPERIMENT

3.1 Subjects

Figure 2 shows the percentage of subjects according to sex and ages and total number of subjects participated in laboratory experiment. Summation of numbers in parenthesis is total number of subjects, or 377.

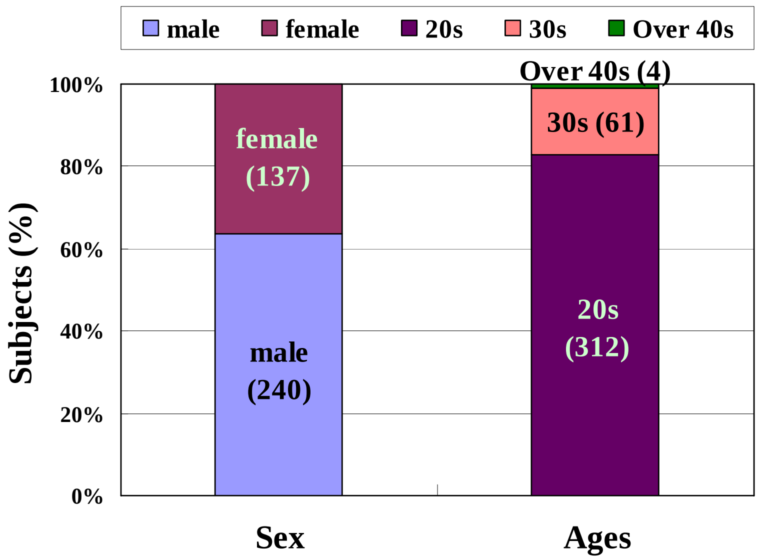

Figure 2: Percentage and total number of subjects participated in laboratory experiment.

3.2 Procedures

The subjects experiment was performed at an anechoic chamber because of disturbance from other noise sources. The size of test section is 3.2 x 3.2 x 2.1 m^3 and cut off frequency is approximately 200 Hz. All of subjects have been tested by 2 sets of stimuli. Subjects were exposed to both monaural and binaural transportation noise and evaluated the extent of annoyance through questionnaire by themselves. Annoyance rating scale adopted in this experiment is 11-points numerical scale, ranging from zero to ten. "10" means "extremely annoyed" and "0" means "not annoyed at all."

4. STATISTICAL ANALYSIS

Linear regression analysis based on WLS (Weighted Least Square) method was conducted. Each mean annoyance score was weighted by the number of data. *Figure 3~5* represent mean annoyance score as a function of A-weighted single event sound exposure level and regression curves. *Table1* shows that relationship (R>0.9) between L_{AE} and mean annoyance was extremely high in all case. Significance of *F*-value in 6 linear regression models shown through *table 2* was less than 0.01 (P<0.05). Consequently, all of linear regression models are significantly effective.

Table 1: Regression equations of three noise sources according to monaural and binaural noise exposure, Y represent mean annoyance scores and X represent A-weighted sound exposure levels

Regressions	Monaural noise exposure	R^2	Binaural noise exposure	R^2
Aircraft	Y = -5.221 + 0.136 X	0.955	Y = -5.156 + 0.146 X	0.987
Railway	Y = -5.086 + 0.142 X	0.937	Y = -6.184 + 0.155 X	0.990
Road traffic	Y = -6.435 + 0.144 X	0.900	Y = -.5221 + 0.162 X	0.924

Table 2: Summery of linear regression analysis about annoyance response to monaural & binaural noise exposure of aircraft, railway and road traffic vehicle

Source	Aircraft		Railway		Road traffic	
Exposure type	Monaural	Binaural	Monaural	Binaural	Monaural	Binaural
S.E	5.3016	2.9742	4.7213	1.9667	5.9709	5.7132
d. f.	(1,8)	(1,8)	(1,8)	(1,8)	(1,7)	(1,7)
F value	170.787	631.842	118.571	823.030	63.281	85.040
Sig. of *F*	< 0.0001	< 0.0001	< 0.0001	< 0.0001	0.002	< 0.0001

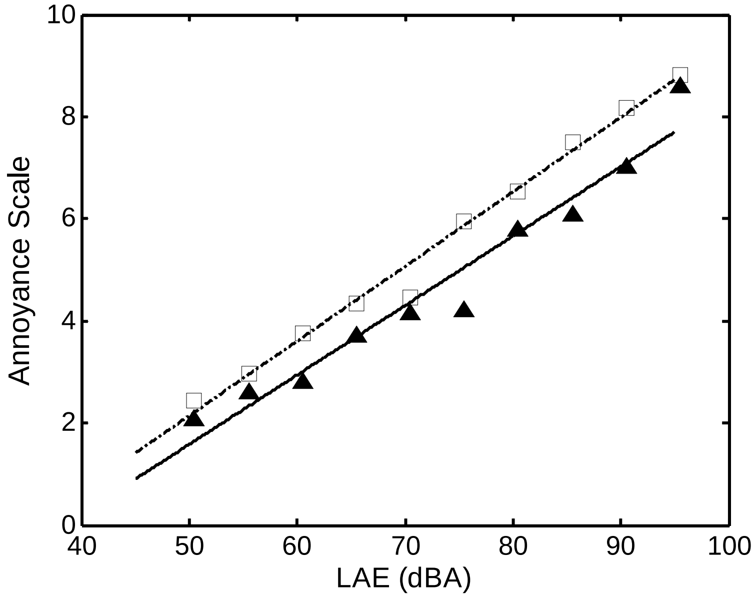

Figure 3: Comparison of mean annoyance score and regressions acquired by monaural and binaural aircraft noise exposures. Solid line represents regressions through monaural aircraft noise exposures and dash dotted line represents regressions through binaural aircraft noise exposures. ▲: *mean annoyance score through monaural aircraft noise exposures,* □: *mean annoyance score through binaural aircraft noise exposures*

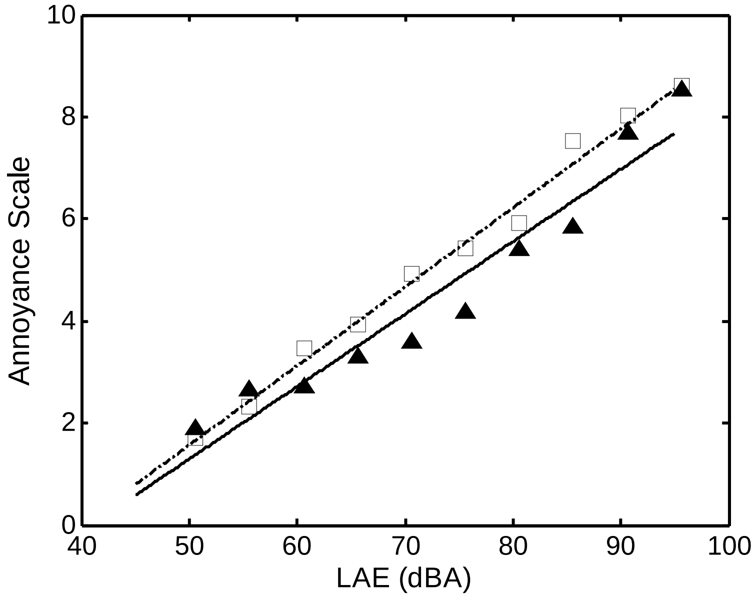

Figure 4: Comparison of mean annoyance score and regressions acquired by monaural and binaural railway noise exposures. Solid line represents regressions through monaural railway noise exposures and dash dotted line represents regressions through binaural railway noise exposures. ▲: *mean annoyance score through monaural railway noise exposures,* □: *mean annoyance score through binaural railway noise exposures*

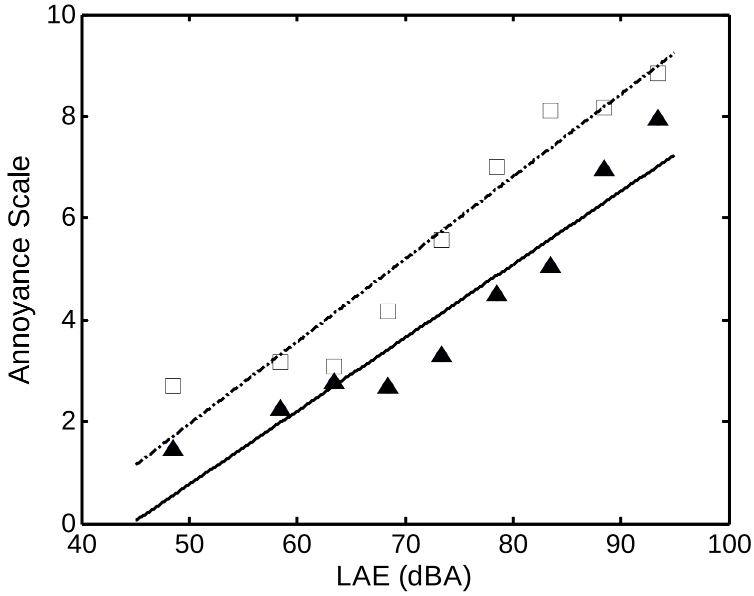

Figure 5: Comparison of mean annoyance score and regressions acquired by monaural and binaural traffic noise exposures. Solid line represents regressions through monaural traffic noise exposures and dash dotted line represents regressions through binaural traffic noise exposures. ▲: *mean annoyance score through monaural traffic noise exposures,* □: *mean annoyance score through binaural traffic noise exposures*

The difference of responses to monaural and binaural sound exposure of each transportation noise source was compared in the *t*-test.

In case of aircraft noise exposure, *F*-value is 1.16 and significance of *F*-value was 0.0071 ($P<0.05$). Variances of annoyance response to monaural and binaural noise exposures were unequal. Under the unequal variance, *t*-value was -7.08 and significance of *t*-value was less than 0.0001 ($P<0.05$). So, the difference of the two cases is statistically significant.

In case of railway noise exposure, *F*-value is 1.03 and significance of *F*-value was 0.7312 ($P>0.05$). Variances of annoyance response to monaural and binaural noise exposures were equal. Under the equal variance, *t*-value was -4.10 and significance of *t*-value was less than 0.0001 ($P<0.05$). So, the difference of the two cases is statistically significant.

In case of road traffic noise exposure, *F*-value is 1.17 and significance of *F*-value was 0.0550 ($P>0.05$). Variances of annoyance response to monaural and binaural noise exposures were equal. Under the equal variance, *t*-value was -3.78 and significance of *t*-value was less than 0.0001 ($P<0.05$). So, the difference of the two cases is statistically significant.

Consequently, monaural and binaural exposures of transportation noise events effects on subjective response to those.

5. CONCLUDING REMARKS

As a result of statistically analysis, *P*-values in all noise sources were less than 0.05. Therefore, it was demonstrated that subjective response to monaural and binaural noise exposure of aircraft, railway and road traffic vehicles is different.

In this paper, it was confirmed that the signal input into human ears was different from measured signal by microphone. Also, the difference of subjective response to monaural and binaural noise exposure was statistically identified through *t*-test of data obtained from laboratory experiment.

Accordingly, when noise levels measured by a microphone are used in assessment of immediate response to transportation noise, correction of binaural effects should be necessary.

ACKNOWLEDGEMENTS

The present study was funded by Ministry of Environment Republic of Korea.

REFERENCES

[1] Markus Bodden, The importance of binaural hearing for noise validation, In: Contributions to Psychological Acoustics. Results of 6th Oldenberg Symposium on Psychological Acoustics. August Schick (ed.), 1. Ed., Oldenberg: Bibliotheksund Informati-onssystem der carl von Ossietzky Universität Oldenberg, 537-554, 1993

[2] J. Robert Stuart, The Psycho-acoustics of Multichannel Audio, JAS 98 Report, 1998

[3] T. J. Schultz, Synthesis of social surveys on noise annoyance, *Journal of the Acoustical Society of America*, **64**(2), 377-405, 1978

[4] S. Fidell, D. S. Barber, and T. J. Schultz, Updating a dosage-effect relationship for the prevalence of annoyance due to general transportation noise, *Journal of the Acoustical Society of America*, **89**(1), 221-233, 1991

[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 Engineering Journal*, **42**(1), 25-30, 1994

[6] Henk M. E. Miedema and Henk Vos, Exposure-response relationships for transportation noise, *Journal of the Acoustical Society of America*, **104**(6), 3432-3445, 1998

[7] G. Labiale, Laboratory study of the influence of noise level and vehicle number and annoyance, *Journal of Sound and Vibration*, **90**(3), 361-371, 1983

[8] E. ÖHSTRÖM, M. BJÖRKMAN and R. RYLANDER, Laboratory annoyance and different traffic noise sources, *Journal of Sound and Vibration*, **70**(3), 334-341, 1980

[9] N. J. Versfeld and J. Vos, A-weighted equivalent sound level as a predictor of the annoyance caused by road traffic consisting of various proportions of light and heavy vehicles, *Journal of Sound and Vibration*, **253**(2), 389-399, 2002

[10] G. M. Aasvang, B. Engdahl, Subjective responses to aircraft noise in an outdoor recreational setting: a combined field and laboratory study, *Journal of Sound and Vibration*, **276**(3-5), 981-996, 2004

[11] ISO 1996-1: 1982, Acoustics - Description and measurement of environmental noise - Part 1: Basic quantities and procedures.

[12] ISO 1996-2:1987/Amd. 1:1998, Acoustics - Description and measurement of environmental noise - Part 2: Acquisition of data pertinent to land use.