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Annoyance modeling of construction noise using acoustical features, noise sensitivity and health condition

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ABSTRACT

The construction site noise is the biggest cause of the noise dispute in Korea. A listening experiment was conducted to produce annoyance prediction models for four kinds of construction noise that cause the most complaints. These noise were generated by the construction machinery such as the pile driver, the excavator, the pumping vehicle, and the concrete mold removal working. These four kinds of noise recorded at the construction site were adjusted to the stimuli with 35 ~ 80 dB(A), and they were played to the subjects and the annoyance score was surveyed. The objective indicators of the stimuli and the survey results of subjects were used as variables to develop the annoyance models caused by construction noise. The annoyance models were developed by multiple regression. Acoustic features include traditional indicators such as Leq, Lmax, as well as indicators of spectral features and temporal features proposed in recent studies. And sound quality indices were used to model. These were calculated mean, maximum, and percentiles values of loudness, sharpness, Roughness and fluctuation strength. Also noise sensitivity and health condition were used as the variables of annoyance prediction models. These were obtained from subjective questionnaire.

Keywords: Construction noise, annoyance, multiple regression, subjective variables

1. INTRODUCTION

Construction noise, which is a mixture of noise generated by various construction machines and works, is generating the most complaints in Korea. In this study, we evaluated the annoyance of construction site noise and investigated the factors affecting the annoyance. There are many previous studies evaluating the annoyanc. "Especially, the method of estimating the degree of annoyance using the% HA curve is useful (1, 2)." The %HA curve predicts annoyance using only noise level, but there are also cases where the annoyance is predicted using other variables. "In case of predicting annoyance using sound quality, explanatory power (R^2) was 0.856(3)." "There are also studies using variables other than the acoustic characteristics of noise stimuli such as gender, experiment time (4)." In this study, we also developed a model to evaluate and predict annoyance using various variables as well as noise level.

Experiments were conducted to evaluate the annoyance of construction noise recorded at the construction site. Two experiments were conducted and the first is an experiment to evaluate the annoyance of single construction machine noise. In the second experiment, combined noise was produced similar to the actual construction site and the subjects evaluated the annoyance.

"'When the noise level is more than 65dBA, the annoyance of complex construction noise is higher than that of single noise.' is reported by Hong JY (5)."

After the experiment, models was developed to predict the annoyance of construction noise by using the acoustic characteristics of the stimulus used in the experiments (objective indicator) and the pre-survey result (subjective indicator). Two types of models were developed using multiple linear regression. The variables of first annoyance model are the acoustical indicators of the noise stimuli used in experiment. In the second model, objective and subjective indicators are used as variables. The subjective variables are the gender, age, and health status of the subjects answered by the participants. After completing the modeling, the explanatory power of each model and the relative importance of the variables were calculated.

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2. EXPERIMENT METHOD

2.1 Recording

The construction noise for the experiments was recorded at the actual construction site. Four kinds of construction noises were recorded in Seoul and the suburbs. The work noise of the excavator and the pile driver used for the civil engineering work, the noise of the concrete pump car used for the construction work, and the noise generated when removing the concrete form were recorded. The noises of pump car and pile driver are continuous sound, the excavator noise and the concrete form falling noise are impulsive sound.

Two-channel microphones (SQuardriga1, BHS1) in the form of headphones were used for binaural recording. Each noise was recorded at around 30 seconds so that no noise other than the target sound was recorded.

2.2 Stimuli for experiment

Since two experiments were conducted, stimuli for each experiment were prepared. The first is an experiment to evaluate annoyance of single noise, and the second is an experiment to evaluate the annoyance of combined noise. In order to use recorded noise for two experiments, four original sounds recorded at the construction site were cut into 10 seconds. Noise stimuli cut into 10 seconds were converted into various noise levels to survey annoyance rate according to level changes.

In Experiment 1, the level of the noise stimulus used in the experiment is 35 ~ 80dBA, and the difference in level between each noise stimulus is 5dBA. The number of stimuli for experiment 1 is 40.

In Experiment 2, two construction noises were mixed for annoyance rating. Two kinds of combined noises were fabricated using single noise stimuli used in Experiment 1. Of the stimuli in Experiment 1, only 50, 60, and 70 dBA were used in the synthesis. Combined noise was produced to include both continuous noise and impulsive noise. The first is a combination of civil engineering noise (pile driver and excavator) and the second is a combination of building construction noise (pumping vehicle and concrete mold falling). The figure 1 below is an example of a combined stimulus. The number of stimuli for second experiment is 12.

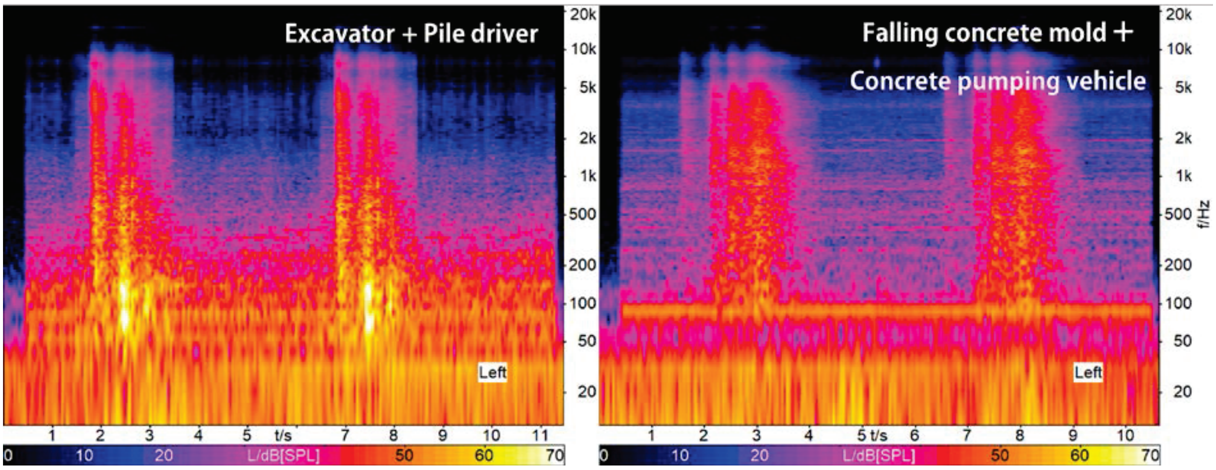

Figure 1 – Example of combined stimuli

2.3 Environment of experiment

The experiment was performed in the auditory test laboratory. The auditory test laboratory consists of a control room and a test room. The background noise level of the test room is around 30dBA. In addition, temperature and humidity environment was kept constant, temperature was about 20 ℃, humidity was about 40%. When the experimenter reproduces the stimulus in the control room, the subject were stimulated in the test room. The subject can hear the noise with a speaker or headphones. In this study, headphones (Sennheiser HD 660s) were used.

Figure 2 – The test room in auditory test laboratory

2.4 Annoyance rating

The experiment was divided into two experiments depending on the type of noise stimulus. It is a single noise experiment that can only hear one construction noise and a combined noise experiment that tells the noise of a combination of two construction noises. In Experiment 1, the subject listened to single construction noise at a time. Subjects in Experiment 2 listened to combined construction noise. Both experiments were conducted to evaluate the annoyance of the subjects after giving them noise stimuli. The subjects participated in the experiment were 60 persons in the single noise experiment and 48 persons in the combined noise experiment.

One of the 40 noise stimuli prepared for the first experiment was randomly reproduced to the subjects and the annoyance score was evaluated using the 11 point scale. In the same way, the annoyance questionnaire for the remaining stimuli was conducted.

In the second experiment, one of the 12 stimuli was randomly presented. The annoyance questionnaire was conducted using the 11 point scale same as in Experiment 1. In the same way, the annoyance questionnaire for the remaining 11 stimuli was performed.

3. RESULTS

3.1 Pre-survey result

Prior to the annoyance questionnaire, subjects were surveyed in advance. In the preliminary questionnaire, the subjects' gender, age, level of education, health condition of the subjects were questioned. In addition, four self-questions related to noise were performed. Self-questions are 'noise sensitivity', 'usual noise exposure level', 'experience of discomfort due to noise', 'experience of sleep disturbance due to noise'.

60 subjects (male 20, female 40) participating in the first experiment have various ages ranging from 10 to 70 years. Of the respondents, 15% said they had a disease and 22% said they were very sensitive to noise. Also, among the subjects more than 20 years old, the proportion of subjects whose education level is higher than that of the university is 68%.

46 subjects (male 22, female 24) participating in the second experiment had an age distribution ranging from 10 to 60 years. The proportion of subjects with the disease is 26%, slightly higher than the first experiment. The ratio of subjects who are very sensitive to noise is 20%, similar to the ratio in Experiment 1. The percentage of highly educated people is 77%.

3.2 Analysis of stimuli used experiment

The acoustic characteristics of the noise stimuli presented to the subjects were analyzed. The analysis items are general noise indicators such as equivalent noise level and maximum noise level, and five psychoacoustic indexes. Loudness and sharpness were analyzed as mean values (L_{mean}, S_{mean}) of stimulus. Roughness and fluctuation strength were analyzed as mean (R_{mean}, F_{mean}), maximum (R_{max}, F_{max}), and percentile values ($R_{10}, R_{50}, R_{90}, \ldots$).

In addition, “the total energy of tonal components within critical bands from 12 to 24 Barks (TETC) was used (6).” “While the loudness and sharpness are calculated using specific loudness of all frequency bands from 0 to 24 Bark, the TETC is calculated by integrating tonal component values of frequency bands from 12 to 24 Barks (6, 7)." These acoustic and psychoacoustic indicators were calculated using Head Acoustics Artemis and statistical package R. Acoustic indicators used for analysis is table 1.

$$\text{Loudness} = \int_0^{24\ \text{Bark}} \text{N}'\,\text{dz} \tag{1}$$

$$\text{Shrapness} = 0.11\frac{\int_0^{24}\text{N}'\text{g(z)}\,\text{dz}}{\int_{12}^{24}\text{N}'\,\text{dz}} \tag{2}$$

$$\text{TETC} = 10log_{10}(\int_{12}^{24} 10^{L(z)/10}\,\text{dz}) \tag{3}$$

Table 1 – Acoustical indicators used in analysis

Acoustic indicator	
Equivalent noise level	L_{eq}
Maximum noise levle	L_{max}
Loudness	L_{mean}
Sharpness	S_{mean}
Roughness	$R_{mean}, R_{max}, R_{10}, R_{50}, R_{90}$
Fluctuation Strength	$F_{mean}, F_{max}, F_{10}, F_{50}, F_{90}$
Total energy of the tonal components	TETC

3.3 Annoyance model

The annoyance prediction model was developed based on the subject's annoyance score, acoustic indicators, and pre-survey results. Multiple regression analysis was used to construct the model and the final model was optimized through the variable selection process. In the initial model with all variables, only the necessary variables were optimized through the backward elimination process.

The annoyance model was developed in two types. The first type model is an objective variable model. The model using the annoyance rating results and the acoustic indicators of the stimuli was produced for each experiment (M_{O1}, M_{O2}). For the second model, both objective and subjective variables were used. Unlike the first model, in which only the acoustic indicators of noise stimuli were used as independent variables, the results of the questionnaire survey were added to the second model (M_{OS1}, M_{OS2}). The variables added to the second type are the results of eight preliminary surveys.

For the M_{O1} model using the acoustic index of the first stimulus, six variables were selected after the variable selection process and the explanatory power (R^2) was 0.7867. In the case of the M_{O2} model using the second experimental results, three variables were selected in the model improvement process and the explanatory power (R^2) was 0.4757. The categorical variable, Source, was selected only on the M_{O1} model, and it was confirmed that the annoyance score was higher when there were file driver noises compared to other types of noise.

In the M_{OS1} model, not only the variables selected in the M_{O1} model but also seven subjective variables were additionally selected. Correlation coefficients show that men are sensitive to noise, and those who have experience of being disturbed by their daily life due to noise are interpreted as more annoying to noise. On the other hand, it was interpreted that subjects with experience of sleep disturbance had lower annoyance. In the case of the M_{OS2} model using the results of Experiment 2, five subjective variables were additionally selected. Unlike the M_{OS1} model, subjective variables for gender and noise sensitivity were removed. The explanatory power (R^2) of the M_{OS2} model is 0.6029, which is higher than that of the M_{O2} model. Table 2 is the annoyance models of experiment 1 and 2.

Table 2 – Annoyance models of experiment 1 and experiment 2

Experiment 1			Experiment 2		
	M_{O1}	**M_{OS1}**		**M_{O2}**	**M_{OS2}**
Variable	Coef.	Coef.	Variable	Coef.	Coef.
Intercept	-4.2187	-5.7642	Intercept	-11.7010	-13.6693
L_{eq}	0.2767	0.2766	Continuous L_{eq}	0.1240	0.1240
Loudness	-0.1347	-0.1346	Impulsive L_{eq}	0.1579	0.1579
Sharpness	5.8745	5.8683	$F_{\max}$	7.1593	7.1593
$R_{\max}$	0.6853	0.6853	Age		0.3879
TETC	-1.3963	-1.3939	Disturb(Yes)		-0.3862
Source(EXC)	1.7829	1.7806	Education(M)		0.3755
Source(PILE)	4.5567	4.5563	Education(H)		-0.9422
Source(PPV)	2.8750	2.8753	Education(U)		0.7240
Gender(M)		0.2519	Education(G)		0.4585
Age		0.0931	Usual noise		0.1522
Disturb(Yes)		0.4379	Sleep(yes)		0.5228
Education(M)		0.8096			
Education(H)		0.3838			
Education(U)		0.4540			
Education(G)		0.5221			
Sensitivity		0.0670			
Usual noise		0.0332			
Sleep(yes)		-0.2011			
R^2	0.7867	0.8018	R^2	0.4757	0.6029
Adjusted R^2	0.7857	0.8002	Adjusted R^2	0.4719	0.5948

3.4 Variables weighting

The relative importance of selected variables for each model was evaluated. "The relative weighting of the variables can be evaluated by making all possible sub-models in the main model and by calculating how much the R^2 value increases on the average when one explanatory variable is added (8)." The calculated relative weighting for each variable are shown in Table 2. The noise level (L_{eq}, dBA) of the stimulus used in the experiment was the most important variable in both models (M_{O1}, M_{OS1}). The second most important variable was R_{max}, followed by Loudness, TETC, and Sharpness. The significance of the variables in the M_{OS1} model using the subjective factors as well as the acoustic characteristics was similar to M_{O1}. The ratio of the subjective variables to the explanatory power of the model was 1.74%.

The noise level of impulsive noise was the most important variable in M_{O2} and M_{OS2} using the second experimental result. Among the subjective variables, the most influential is the age, and the higher the age, the higher the annoyance level. In the M_{OS2} model, the ratio of the subjective variables to the explanatory power of the model is 18%, which is higher than that of the M_{OS1} model. This is interpreted to be due to the fact that the number of acoustic indicators selected for M_{OS2} is three, which is small compared to the model of Experiment 1.

Table 3 – Weight of variables each model

Variable	Weight (%) M_{O1}	Weight (%) M_{OS1}	Variable	Weight (%) M_{O2}	Weight (%) M_{OS2}
L_{eq}	22.04	21.66	Continuous L_{eq}	38.83	31.81
Loudness	19.24	18.91	Impulsive L_{eq}	45.16	36.99
Sharpness	15.03	14.75	$F_{\max}$	16.01	13.12
$R_{\max}$	21.90	21.52	Age		13.25
TETC	15.03	18.25	Disturb		0.41
Source	3.23	3.17	Education		1.78
Gender		0.15	Usual noise		2.21
Age		0.41	Sleep		0.41
Disturb		0.46			
Education		0.06			
Sensitivity		0.36			
Usual noise		0.27			
Sleep		0.03			

4. CONCLUSION

Four kinds of noise from the construction site were recorded and two experiments were conducted. In the first experiment, the subject listened to one kind of noise stimulus and then evaluated the annoyance. In the second experiment, he listened to the combined noise stimulus and then evaluated the annoyance. Models using objective variables and models using objective and subjective variables were developed using the annoyance results of each experiment. Four models are developed, M_{O1} and M_{O2} are objective variable model, and M_{OS1} and M_{OS2} are subjective variable model.

The explanatory power of M_{O1} and M_{O2} are 0.79 and 0.48, respectively. The explanatory power of M_{OS1}, M_{OS2} was 0.80 and 0.60, which is higher than M_{O1} and M_{O2}. The explanatory power of M_{OS1} increased by 0.015, while the R^2 of M_{OS2} increased by 0.13.Commonly selected subjective variables after variable selection are age, education level, sleep disturbance experience due to noise. However, there is a case where the correlation coefficient between the performance score and the score is opposite.

The relative importance of each variable in the explanatory power of the model was evaluated. In common, the most important variable was the magnitude of the stimulus (noise level). The importance of subjective variables was 1.74% in M_{OS1} and 18% in M_{OS2}, which was relatively low compared to the acoustical indicators. Since the explanatory power of the model is not significantly improved and the ratio of the subjective variables to the explanatory power is also low, it is judged that the subjective variables have little influence on the evaluation of the annoyance of the single noise. In M_{OS2}, the ratio of the subjective variables to the explanatory power is higher than that of M_{OS1}, but the explanatory power of the model itself is low. Acoustic indicators and subjective variables were statistically significant when evaluating the annoyance from construction noise, but the relative importance of subjective variables is lower than acoustic indicators.

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