Psychoacoustical evaluation of heavyweight floor impact sounds in apartment buildings

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ABSTRACT

An auditory experiment was conducted to establish annoyance criteria for floor impact noise in apartment buildings. Heavyweight floor impact sounds were recorded using an impact ball; the impact sound pressure level (SPL) together with the temporal decay rate (DR), which is quantified by the dB drop per second, was analyzed. For the experiment, A-weighted exposure levels of the heavyweight floor impact sounds ranging 34–73 dB were evaluated at 3 dB intervals. Participants used a 7-point verbal scale to evaluate the level of annoyance from floor impact noise. The results show that the annoyance increases with increasing impact SPL and decreasing DR. Consequently, a classification and an acceptable level of floor impact sounds were proposed.

Keywords: Floor impact Sound, annoyance, classification I-INCE Classification of Subjects Number(s): 51.3

1. INTRODUCTION

Floor impact sounds are one of the most annoying noises in apartment buildings. In particular, a number of complaints by residents over heavy-weight impact sounds, generated from adults walking or children running and jumping, have increased steadily in Korea. For evaluation of heavy-weight impact sounds, standard impact sources such as a bang machine and impact ball (heavy/soft impact source) have been used. In general, loudness of impact noise is the most critical factors affecting perception of noise and the perception of the loudness of impact noises may be affected by maximum sound pressure level (L_{max}) (1-3). Even though the sound pressure level is the same, subjective responses to floor impact sounds can be different. Several studies have been conducted to investigate the effect of various factors including spectral, spatial, and temporal characteristics on subjective responses to heavy-weight impact sounds. Kim et al. (3) revealed that sound pressure level and the temporal decay rate of floor impact sounds significantly influence annoyance perception. It was also found that annoyance of impact sounds can be reduced with increasing DR, by controlling the sound field of the receiving room. Reverberation time of the room in apartments ranged from 0.5 to 1.5 sec in variation of the arrangement of furniture and circumstances furniture in the previous study (4). Although classification of overall dissatisfaction with indoor noise environment in residential buildings was suggested (5), a few studies to classify the floor impact noise levels based on annoyance have concerning both sound pressure level and temporal decay rate. In particular, there is considerable need to suggest acceptable limit of floor impact sound levels to solve the conflicts among residents living in apartments. Thus, in this study, a laboratory test was performed to evaluate annoyance and acceptable limit in variation of sound pressure level and temporal decay rates.

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2. METHODOLOGY

2.1 Experimental design

Noise annoyance and acceptable limits of level for heavy-weight floor impact sounds were investigated based on auditory experiment in a laboratory condition. Acoustic stimuli were created using heavy-weight impact sound recorded in apartment buildings with a box-framed type reinforced concrete structure using a rubber ball which was classified into spectrum type II in the previous study (6). The impact sound was recorded in the center of the room using a 1/2 inch microphone (B&K type 4189) and head and torso simulator (HATS, B&K type 4100) as generated by a rubber ball from the center of the upstairs room for the auditory experiment.

Two factors affecting perception of heavy-weight floor impact sounds were taken into account: noise levels and decay rates of stimuli. Two-factorial design was scheduled for the experiment. L_{Amax} of acoustic stimuli were varied from 34 to 73 in increasing step of 3 dBA. Decay rate (DR) was used to quantify the temporal decay of impact sounds. DRs for the stimuli were set at 30 and 60 dB/s, respectively because more than 70% of the ball sound DRs were in the range from 30 to 60 dB/s [3].

In total, 28 stimuli were created for the experiment. Each stimulus was separated by an interval of 5 s and presented in random order. Noise annoyance was assessed using 7-pt. verbal scale (0: not at all, 1: insignificantly, 2: somewhat, 3: moderately, 4: considerably 5: highly, 6: extremely) with following question: “How much do you annoying, if you imagine that you were exposed to it in the living room?” In addition, acceptable limit of level for impact sounds were evaluated with the following question: “Is this sound level acceptable?” using a binary scale (acceptable: 1, not acceptable: 0).

2.2 Procedure

Thirty subjects aged 20s-30s participated in the experiment. Before the experiment, all participants tested their hearing threshold level with the use of an audiometer (Rion AA-77). The results showed that all participants had normal hearing. The experiments were performed in a testing booth with a low background noise of approximately 25 dBA (L_{Aeq}), and the sound stimuli were presented using headphones (Sennheiser HD-650). A high-pass filter and a low-pass filter, in which the cut-off frequency was 63 Hz in the octave band, were applied to the sounds reproduced by the headphones.

3. Results

3.1 Noise annoyance for heavy-weight floor impact sounds

Mean annoyance ratings for the floor impact sounds in terms of different decay rates appear in Table 1. In general, annoyance increased as L_{Amax} of stimuli increased as shown Figure 1. Significant mean differences regarding DR were not found below L_{Amax} of 61 dBA, while statistically significant differences were found above 67 dBA at the level of 0.01. The floor impact sounds of DR 30 were evaluaed as more annoying than those of DR 60. This implies that effect of DR is not significant when sound levels of floor impact sounds are below 60 dBA. These results are somewhat contrast to the result in the previous study (3) hat the contribution of DR is significant on the annoyance of floor impact sounds. This might be caused by the annoyance evaluation methods that Kim et al. (3) adopted paried comparison methods using nine acoustic stimuli while Likert scale was used in the present study. Paired comparison method is relatively more useful than rating method to discriminate the subjects’ perception with stimuli where priorities are not clear.

Table 1 – Mean annoyance ratings in terms of SPL and DR

L_{Amax} [dBA]	34	37	40	43	46	49	52	55	58	61	64	67	70	73
DR 30	0.7	1.0	1.5	1.6	2.2	2.6	2.8	3.3	4.0	4.2	5.1	5.5	5.8	6.0
DR 60	0.8	1.0	1.3	1.6	1.9	2.2	2.8	3.3	3.9	3.9	4.6	4.8	5.4	5.7

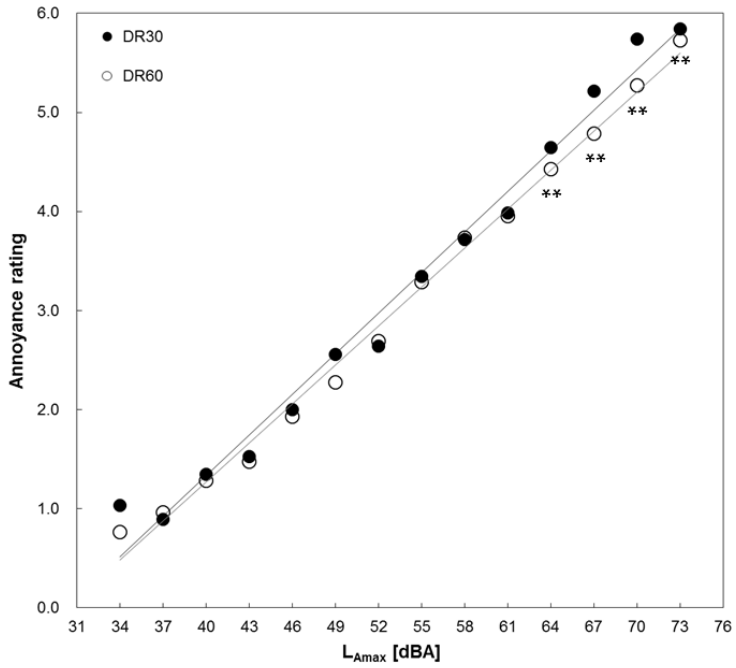

Figure 1 – mean annoyance rating as a function of noise levels (*p<0.05, **p<0.01)

Figure 2(a) shows the percentage of annoyed subjects who gave a rating ‘3: moderately’ or higher on 7-pt. scale (%A) as a function of L_{Amax} regarding DRs and it was revealed that there was no significant difference between the results in terms of DR. Percentage of highly annoyed subjects who gave a rating ‘4: considerably’ or higher on 7-pt. scale (%HA) as a function of L_{Amax} regarding DRs was plotted in Figure 2(b). Compared to the result of %A, %HA of DR 30 dB/s was higher than that of DR 60 dB/s. This confirms that heavy-weight floor impact sounds decayed rapidly are perceived to be less annoying.

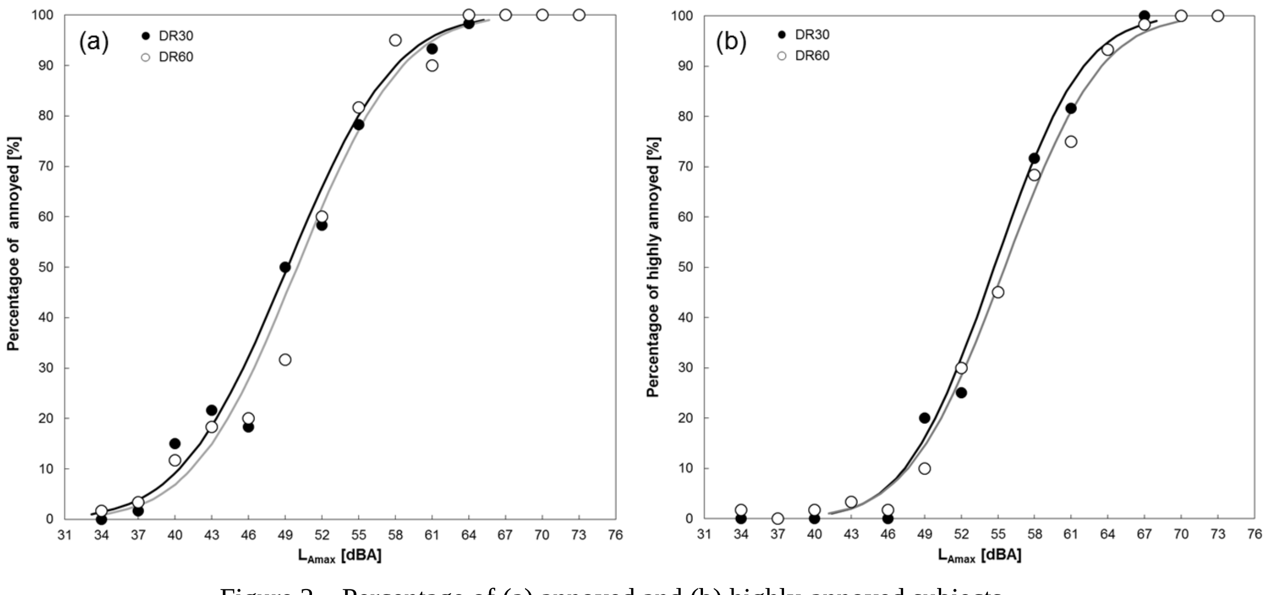

Figure 2 – Percentage of (a) annoyed and (b) highly-annoyed subjects

Table 2 and 3 describe the classification of annoyance for heavy-weight floor impact sounds based on the dose-response curve of %A and %HA, respectively. Annoyance were classified into four levels with 25 % interval of %A and %HA and the noise levels of floor impact sounds for each class corresponding to the percentage of annoyance obtained from the laboratory experiment were estimated. Class A indicates less than 25 % of the subjects evaluated the stimuli as annoying or highly annoying indicates good acoustic condition, while Class D denotes more than 75 % of the subject annoying or highly annoying judged the stimuli representing the worst acoustic condition in terms of annoyance. The difference of L_{Amax} between DR 30 dB/s and 60 dB/s was approximately 1 dBA in each class.

Table 2 – Classification of annoyance for heavy-weight floor impact (%A)

Class	%A	L_{Amax} [dBA]		
		DR30	**DR60**	**Total**
A	0 - 25%	< 44.5	< 45.4	< 45.0
B	25 - 50%	< 49.2	< 50.0	< 49.6
C	50 - 75%	< 53.8	< 54.5	< 54.2
D	75 - 100%	> 53.8	> 54.5	> 54.2

Table 3 – Classification of annoyance for heavy-weight floor impact sounds (%HA)

Class	%HA	L_{Amax} [dBA]		
		DR30	**DR60**	**Total**
A	0 - 25%	< 50.9	< 51.4	< 51.1
B	25 - 50%	< 54.7	< 55.6	< 55.1
C	50 - 75%	< 58.6	< 59.7	< 59.2
D	75 - 100%	> 58.6	> 59.7	> 59.2

3.2 Acceptable limit of level for heavy-weight floor impact sounds

Percentages of the subjects who judge the impact sound is acceptable as a function of L_{Amax} were illustrated in Figure 3. There was no significant difference between DR 30 and 60 dB/s. As L_{Amax} of heavy-weight floor impact sounds increased, percentage of acceptability decreased. The noise level when the half of the subject perceived the noise level to be acceptable was 49.7 dBA. This indicates that the L_{Amax} of heavy-weight floor impact sounds should be reduced less than 50 dBA to obtain more than 50 % of acceptability. Approximately, 50 dBA of floor impact sounds corresponds to Class B and A based of the classifications based on %A and %HA, respectively. This indicates that Class B - D in classifications of annoyance based on %HA are not satisfying the 50 % of acceptability except Class A. Meanwhile, Class C and D in classifications based on %A cannot meet the 50 % of acceptability. Considering ability to discriminate the annoyance levels of floor impact sounds, suggested classification of %A might be more appropriate.

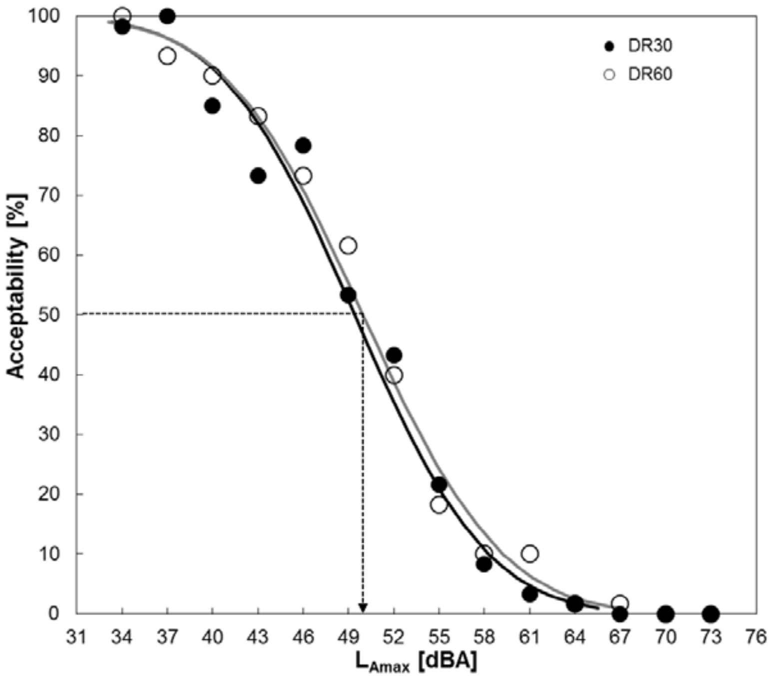

Figure 3 – Percentage of acceptability as a function of noise levels

4. Conclusions

In the present study, classification of noise annoyance level and acceptable limit of level for heavy-weight floor impact sounds were explored as a function of L_{Amax} and DR based on laboratory tests. Annoyance rating scores increased as the sound levels increased. The effect of DR on annoyance was found when the floor impact sound levels are larger than 60 dBA. Class A-D of heavy-weight floor impact sounds in terms of annoyance were suggested based on the percentage of %A and %HA, It was found that classification based on %A would be more useful to evaluate the heavy-weight floor impact sounds concerning the fact that acceptable limit of L_{Amax} for heavy-weight floor impact sounds was approximately 50 dBA.

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