중량충격음 어노이언스 반응에 대한 IACC 변화의 영향
Effects of IACC and its Variation on Annoyance of Heavy-weight Floor Impact Sounds

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Key words : Floor Impact Sound (충격원), Annoyance (어노이언스), Interaural Cross-correlation (IACC), Variation of IACC (IACC 의 변이)

ABSTRACT

This study investigates the effects of Interaural Cross-correlation (IACC) and its variation on annoyance of the heavy-weight impact sounds. Subjects evaluated the annoyance of the heavy-weight floor impact sounds recorded in rooms of apartments which have different sound insulation treatments; furnished and occupied conditions are characterized by the ACF/IACF factors. A paired comparison test was conducted using the impact sound sources whose IACC and variation of IACC values were different. It was found that IACC is inversely correlated with the scale value (r = -0.62) whereas the variation of IACC is not (r = -0.34). On the contrary, Φ(0) is highly correlated with scale value of annoyance and Φ(0) is need to be controlled as constant to find the effect of IACC on annoyance.

1. Introduction

Floor impact sound caused by adult's walking, children's running and jumping is considered to be most irritating among the noise in apartment buildings in Korea. The box-frame-type reinforced concrete structure, with retaining walls instead of beams and columns is the unique structural design in Korean apartments. To record floor impact sounds bang machine and impact ball recommended in Japanese Industrial Standard (JIS A 1418-2:2000[1-2]) and Korean Standard, (KS F 2810-2) have been utilized as standard impactors.

So far floor impact sound has been evaluated according to the sound pressure level and frequency characteristics. Besides of noise level, temporal sensation (loudness, pitch, timbre and duration) and spatial sensation (sound localization, apparent source width and subjective diffuseness) also affect the perception of sound. These functions are closely related to ACF/IACF (autocorrelation function/interaural cross-correlation function) factors[3-6]. Jeon et al.[7-8] used the ACF/IACF factors of floor impact sound from standard impact sources and examined the relationship between ACF/IACF, sound quality metrices and loudness. Jeon et al.[9] also found that reduction in sound from the floor and walls minimizes the loudness and annoyance. Furthermore, Sato and Jeon[10] found that the τ_1 and τ_e have the greater influence on annoyance as well as Φ(0) and loudness. These results show that there is a need to find the effect of spatial parameters i.e., IACC on subjective evaluation of heavy-weight floor impact sound.

Spatial subjective attributes such as spaciousness, source width and source direction can be evaluated by IACF and binaural measurements. IACC represents the

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degree of similarity of sound waves arriving at both ears and hence it is a significant factor determining the perceived horizontal direction of a sound and the degree of subjective diffuseness. Apparent source width of a sound can be well defined by W_{IACC} (width of interaural cross-correlation) and IACC. The main objective of this paper is to evaluate the effect of IACC and its variation on perception of heavy-weight floor impact sound. This is found by controlling other ACF/IACF factors and sound level of each source. In order to obtain the scale value of annoyance paired comparison test is conducted by which the effect of IACC and its variation on perception of floor impact sound is evaluated.

2. Measurement Procedure

In measuring floor impact sounds, bang machine and impact ball standardized have been utilized. The floor impact was generated at the center of the upstairs room and the sound was measured and recorded binaurally through dummy head (B&K 4100) placed at the center point of the downstairs room. In order to find the effect of IACC of heavy-weight floor impact noise the recorded sounds are summarized and the other IACF factors are controlled for the auditory test.

Measuring and recording were performed in various rooms of apartments in Korea and in a testing facility, which are reinforced concrete structures. 15 suites of apartments and a suite of testing facility with different flooring conditions were selected for floor impact sound measurements. The apartment floors consist of reinforced concrete slab (thickness of 150 mm) and wooden flooring. The floor of testing facility consists of reinforced concrete slab thickness of 150, 180, 210 and 240 mm with and without flooring.

3. ACF/IACF Factors

To analyze the physical characteristics of heavy-weight floor impact sound ACF/IACF factors are used for evaluation. It consists of 8 factors which deal with the temporal and spatial sensations. The first and second ACF factors are the delay time and the amplitude of the first dominant peak of the normalized ACF, τ_1 and ϕ_1 illustrated in Figure 1. The third ACF factor is τ_e, the *effective duration which is defined by the 10-percentile* delay representing a repetitive feature of reverberation within the source signal itself. The forth is $\Phi(0)$, energy *represented at the origin of the delay.* When spatial factors are concerned, IACC represents the magnitude of the inter-aural cross-correlation, τ_{IACC} is inter-aural delay *time at which the IACC is defined.* W_{IACC} is width of IACF at the τ_{IACC} as illustrated in Figure 2.

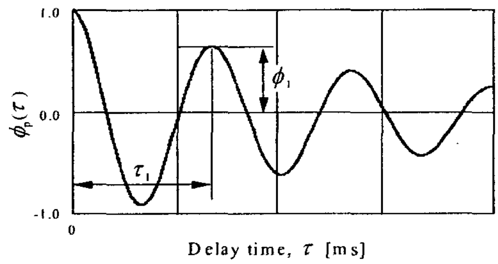


Fig. 1 Definition of ACF factors.

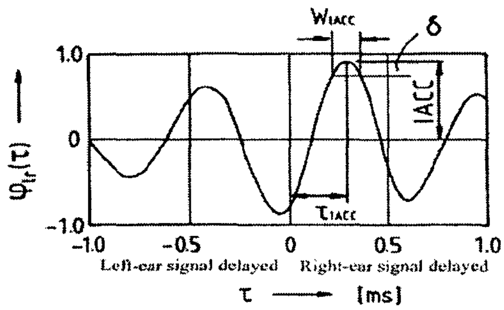


Fig. 2 Definition of IACC, τ_{IACC} and W_{IACC}.

Figure 3 shows the IACC and variation of IACC of impact ball and bang machine of eleven selected sound sources. The analysis shows that there is variation of IACC in impact ball with the thickness of the slab and similarly to the bang machine. It even shows the difference of effect of impact ball and bang machine under same flooring condition. In an apartment we induced a floating floor which is generally used for its effectiveness in controlling structure-borne and airborne noise. The selected suites are of different conditions like fully completed, partially completed (surface of flooring and walls not finished), furnished and occupied are considered.

The duration of each sound is taken as 1.5 s. The initial 0.5 s of the floor impact sound with 10 ms steps, and thus, 50 running ACF/IACF factors were obtained for each sound. In order to find the effect of IACC on annoyance the other ACF/IACF factors are controlled by summarization of sound source. 176 sound sources of impact ball and bang machine are classified according to average τ_1 value of each sound. The sound sources with value of τ_1 20±1 ms are taken for auditory test since lower the τ_1 value higher the pitch of the sound sources. The sound sources with variance of τ_1 less than 0.5 ms are taken in order to control the effect of fluctuation and variance of τ_1. as shown in Figure 4. The IACC of sound sources is controlled by selecting sources with high variation and by avoiding the similar IACC and variation of IACC value of sound sources. Due to summarization 11 sound stimuli from 176 floor impact noise sources recorded from different structures are selected for the auditory experiment. The value of IACC and its variation of selected sound sources are shown in Figure 3

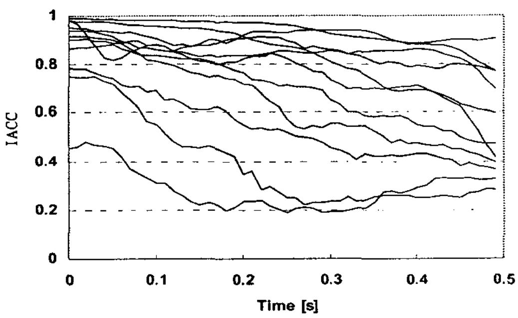


Fig. 3 IACC values of selected sound sources.

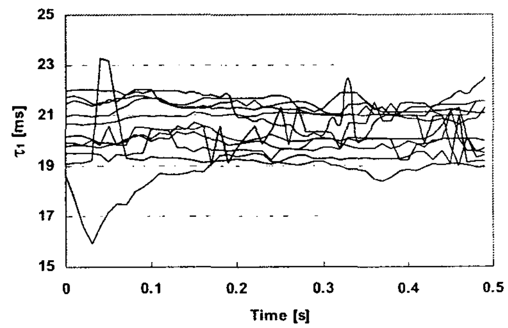


Fig. 4 τ_1 values of selected sound sources.

4. Auditory Experiment

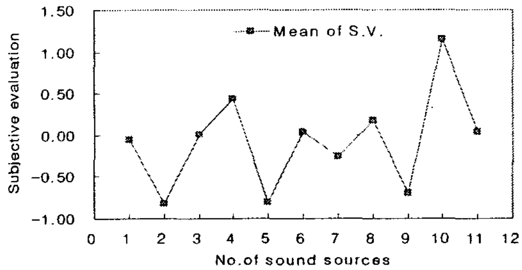
A subjective evaluation was conducted in a sound proof chamber. The sound source for the binaural hearing experiment was presented to subjects through headphone (Sennheiser HD-600). A desktop computer with MEDS (Musical Experiment Development System) was used to record the responses of the subjects.

A paired comparison method was used to investigate the subjective evaluation of sound sources. The 11 comparison sound sources form 55 pairs for the auditory experiment. The impact sounds presented by the headphone were recorded by dummy head and analyzed by ACF/IACF factors to check the objective parameters of the possible experimental errors. The sound level of each sound source was controlled at a constant L_{Aeq} level of 58 dBA. The purpose of this comparison is to verify the scale value of annoyance with IACC and its variation. Each pair was presented such that every impulse sound of 1.5 s duration was played three times continuously and with 0.5 s of inter-stimulus interval and the next sound source was played respectively similar as previous one. The duration of each pair was 9.5 s (4.5+0.5+4.5) and the total test duration was about 12 minutes. Each subject was asked to select which one of sound source in each pair is perceived to be more annoying. The subjects were asked to assume as if they are relaxing in their own house. The test was participated by 10 subjects who experienced such auditory experiments and live in apartments.

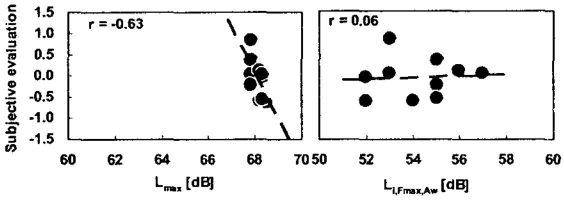
6. Results

Fifty five responses from a paired comparison test were obtained from each subject. The consistency test indicated that all the subjects had a significant ability for distinguishing between various degrees of annoyance ($p < 0.05$) and also had a significant agreement among subjects ($p < 0.05$). A scale value of annoyance was developed by applying the law of comparative judgment (Thurstone's case V).

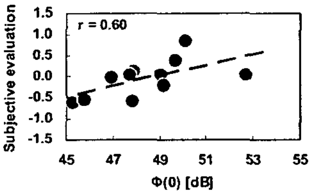
The correlation among the subjective evaluation of floor impact sound sources and physical factors were obtained by the analysis. Figure 5 shows the effect of different sound sources on annoyance.



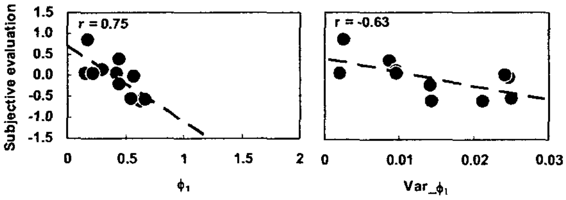
. **Fig. 5** Scale value of annoyance for each stimulus.



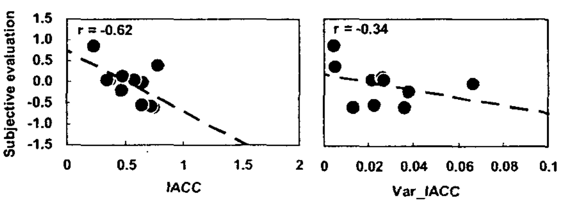
(a) L_{max} (b) $L_{i,Fmax,Aw}$



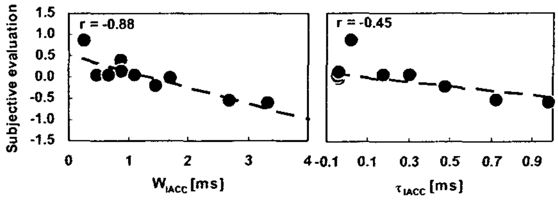
(c) Φ(0)



(d) ϕ_1 (e) Var_ϕ_1



(f) IACC (g) Var_IACC



(h) W_{IACC} (i) τ_{IACC}

Fig. 6 Subjective evaluation of floor impact noises correlated with ACF/IACF factors.

Figure 6 shows high correlation of subjective evaluation with ACF/IACF factors. Figure 6(a) shows the relation between subjective response and L_{max} (r = -0.64). The *negative correlation reveals that scale value is inversely* proportional to L_{max}. From Figure 6(c) it reveals that the subjective evaluation of floor impact noise is highly correlated with Φ(0) (r = 0.60). As shown in Figures 6(d)-(i), it also reveals that ϕ_1 (r = -0.75), IACC (r = -0.62), W_{IACC} (r = -0.88) and variation of ϕ_1 (r = -0.63) are highly correlated with scale value. This means that the decrease in values in those factors increases the scale value of annoyance. Table 2 shows the correlation coefficient of scale value with ACF/IACF factors. It reveals that correlation coefficient of Φ(0) is highly correlated with other ACF/IACF factors.

Table 2 Correlation coefficient between scale value and ACF/IACF factors

Factors	S.V	L_{max}	$L_{i,Fmax,Aw}$	Φ(0)	ϕ_1	IACC	W_{IACC}	τ_{IACC}
L_{max}	-0.63	1.00						
$L_{i,Fmax,Aw}$	0.06	-0.49	1.00					
Φ(0)	0.60	-0.89	0.55	1.00				
ϕ_1	-0.75	0.53	-0.38	-0.70	1.00			
IACC	-0.62	0.41	-0.18	-0.54	0.88	1.00		
W_{IACC}	-0.88	0.69	-0.32	-0.78	0.89	0.73	1.00	
τ_{IACC}	-0.45	0.40	-0.13	-0.47	0.16	0.07	0.48	1.00
Var IACC	-0.34	0.31	-0.22	-0.25	0.36	0.15	0.20	-0.18

Results of the correlation coefficients indicate that the effect of Φ(0), ϕ_1, IACC, W_{IACC} is highly correlated with scale value among the ACF factors. In this study $L_{i,Fmax,Aw}$

and Φ(0) had a variation of 5 and 8 dB, respectively in the current level ranges even though the value of L_{Aeq} was controlled at 58 dBA. Consequently the correlation of $L_{i,Fmax,Aw}$ is not significant which indicates that $L_{i,Fmax,Aw}$ has less effect on subjective perception.

The correlation coefficient of Φ(0) with other ACF factors indicated that Φ(0) is more dominant. The correlation coefficient of Φ(0) with IACC (-0.54), ϕ_1 (-0.70), W_{IACC} (-0.78) and L_{max} (-0.89) which shows that these factors are inversely correlated to Φ(0).

7. Discussion and Conclusions

In order to find the effect of IACC and its variation on annoyance Φ(0) should be fixed constant. The impact sounds are controlled by amplifying the sounds to the constant average maximum Φ(0) level .

From the further work we may investigate the effect of IACC and its variation on annoyance by controlling Φ(0) value. In order to find the effect of IACC of floor impact sound the relation between the heavy-weight impact sound and human made sound will be investigated.

The effect of children's running, walking, jumping, jump from chair, as human made sound and tapping machine can be influenced by IACC and need to be considered. Hence recording of human made sound and tapping machine in apartments are conducted and the analysis is under process.The further work is on comparison of heavy-weight impact sound and human made impact sound with respective to effect of IACC. Φ(0) should also be controlled effectively as constant.

As conclusion, it was found that:

- Annoyance of floor impact sound was highly correlated with Φ(0) even though the level of L_{Aeq} was controlled as constant 58 dBA for all sources.

- In order to find the effect of IACC and its variation of IACC on annoyance control of other binaural factors such as W_{IACC} and τ_{IACC} must be more precise.

- IACC, ϕ_1, W_{IACC} are inversely correlated with scale value of annoyance and hence when these factors decrease their scale values increases.

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