Masking Effect of Artificial and Natural Sounds on Residential Noises

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Summary
This study investigated the effect of artificial and natural sounds on masking of residential noises through auditory experiments. Residential noises consists of floor impact noise (children jumping), TV sound, toilet flushing noise, and road traffic noise. As making sounds, white, pink, and brown noises were used for artificial sound, and waterfall, stream, wave, rain, insect, and bird sounds were also included for natural sound. In the auditory experiment, thirty subjects rated first their preference and annoyance of the artificial and natural sound as masking sound. Then, the subjects also rated annoyance for combined sound consisting of the residential noise and the natural or artificial sound with various masker-to-noise ratios (MNR) from -3 to +3 dB (3 dB step). It was found that most masking sounds can reduce annoyance of the residential noise. In addition, the masking effect was observed even when sound level of making sound was -3 dB lower than that of the residential noise. However, the masking effect was strongly dependent on masking and residential sound types.

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1. Introduction

In multi-story residential building such as apartment building, many kinds of noises were occurred. The noise sources consist of floor impact, airborne, drainage, and outdoor noise. Although various noise isolation techniques have been applied in the construction of apartment building, resident's satisfaction of sound environment is not so high in Korea. Meanwhile, masking method to reduce the adverse effect from noise has been studied in the soundscape research area. Water and bird chirp sounds were introduced as the masking sound for urban noise such as traffic noise and have an effect on improving perceived soundscape quality [1-5]. The optimal masker-to-noise ratio (MNR) between natural sounds and urban noise was also investigated [5].
This study investigated the masking effect of natural sounds on residential noise through auditory experiment. In the auditory experiment, subjects rated their annoyance for residential noise with and without the artificial or natural sound as making sound with various MNR. In addition, subjective preference and annoyance of the natural and artificial sound was evaluated, and its relation with masking effect was explored. The MNR between artificial and natural sounds (masker), and residential noise was also analyzed to achieve annoyance reduction of residential noise.

2. Method

The auditory experiment was conducted in the laboratory. The residential noises consists of floor impact noise (children jumping), TV, toilet flushing, and road traffic noise. As making sounds, white, pink, and brown noises were used for artificial sound, and waterfall, stream, wave, rain-fall, insect, and bird sounds were also included for natural sound. The residential noises were recorded in the center position of a living room or bathroom of an apartment building. A child's jumping sound and toilet flushing noise from upper unit was recorded in the living room and bathroom, respectively. TV sound with man's announcement and road traffic noise with car speed of 60 km/h (in closed window condition) were also recorded in the living room. The artificial sounds were made using sound editing software (Adobe Audition ver. 1.5), and natural sounds were collected in the Korean governmental website, which provides many kinds of natural sounds recorded in Korea. All sounds were edited in 5 seconds, and the residential noise were combined with artificial and natural sounds using

the sound editing software. The MNR between artificial and natural sounds (masker), and residential noise ranged from −3 dB to +3 dB with 3 dB steps. Sound pressure level of residential noise presented in the auditory experiment was 57 dBA (L_{Amax}) for floor impact noise and 45 dBA (L_{Aeq}) for the other noises. These sound pressure levels are limits of noise regulation of Korean government for the residential noise inside room of dwelling.
Thirty subjects in their 20's with normal hearing participated in the auditory experiment. The subjects were asked to rate the followings for stimuli.

- Preference and annoyance of the artificial and natural sound as masking sound
- Annoyance of the residential noise
- Annoyance of combined sound of residential noise and the artificial or natural sound with various MNR (from −3 dB to +3 dB with 3 dB steps)

In first and second annoyance rating, 9 stimuli (3 artificial and 6 natural sounds) and 4 stimuli (residential noise) were present in random order to subject, respectively. Third annoyance rating consisted of 4 sessions. Each session was for one residential noise among four residential noises, and had 63 stimuli (9 masking sounds of artificial and natural sound × 7 MNRs), which were presented in random order. All stimuli were presented with headphone (Sennheiser HD 600), and the Korean verbal scale with 7 points was used for subject's annoyance rating.

3. Results and discussions

3.1. Preference of masking sound

Figure 1 illustrates the preference of artificial and natural sound as masking sound. As shown in Figure 1, the preference score of artificial sound such as white, pink, and brown noise was low. On the other hands, stream, bird, and rain sound were relatively preferred.

3.2. Annoyance of combined sound in equal sound pressure level

Figure 2 shows the relative annoyance of combined sound of residential noise and masking sound in equal sound pressure level to the residential noise. The presented sound pressure level of residential noise was 57 dBA (L_{Amax}) for jumping sound and 45 dBA (L_{Aeq}) for the other noises. The relative annoyance was calculated by subtracting annoyance of single

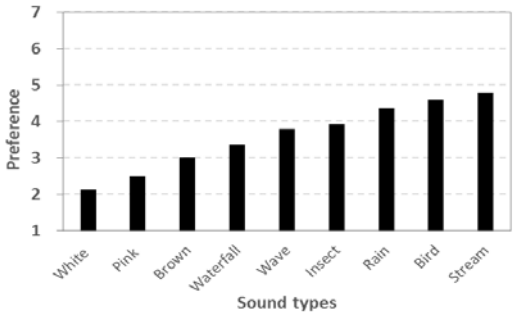

Figure 1. Preference of artificial and natural sound as masking sound.

residential noise from annoyance of the combined sound ($annoyance_{combined} - annoyance_{residential}$). In Figure 2, asterisk indicates statistically significant differences in annoyance ($p < 0.01$). As shown in Figure 2, annoyance of combined sound was significantly lower than that of the single residential noise in most case. This result indicates that masking sound can reduce annoyance of residential noise. On the other hands, in several cases the annoyance between single residential noise and combined sound was not significantly difference, and white noise increased annoyance in particular.
However, the masking sound type with reduction of annoyance varied with the residential noise types. Figure 2 indicates that stream and wave sound reduced the annoyance for all residential noises. On the other hands, white noise, bird, and insect sound failed to reduce the annoyance for all residential noises. Rain sound, brown, and pink noise also reduced the annoyance for three types of residential noise, excluding TV sound. In addition, waterfall sound reduced the annoyance for toilet and jumping noise.
Table 1 shows the correlation coefficient between preference of masking sound and annoyance of combined sound of the residential noise and masking sound. For all masking sounds, the preference of masking sound was negatively correlated with annoyance of combined sound only for TV and road sound. However, for six masking sounds excluding stream and bird sound, and brown noise, the coefficients were significantly increased.

Table I. Correlation coefficient between preference of masking sound and annoyance of combined sound of the residential noise and masking sound (for all and six masking sound excluding stream and bird sound, and brown noise)

Masker	TV	Road	Toilet	Jumping
All	-0.57	-0.52	0.02	0.04
Six	-0.78	-0.86	-0.66	-0.50

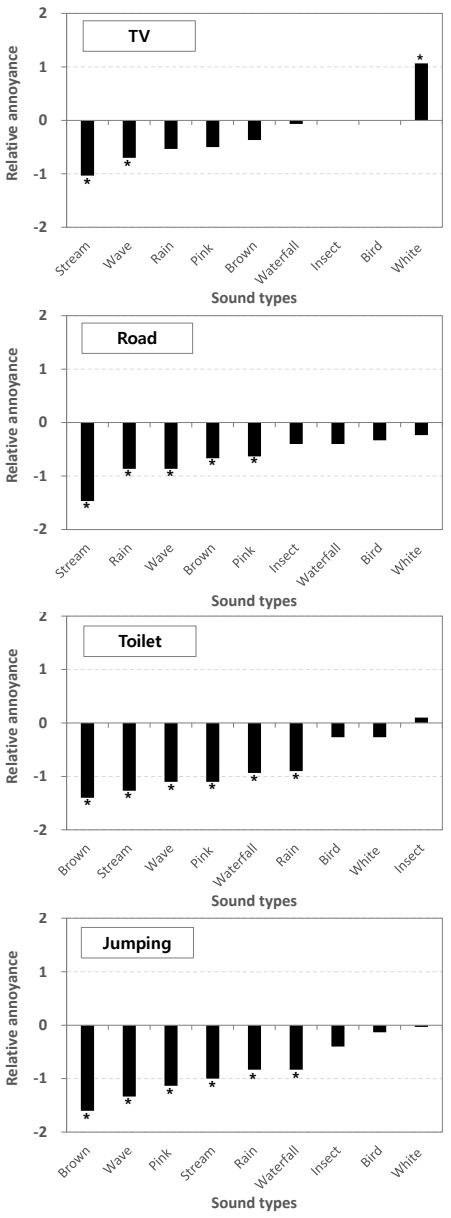

Figure 2. Relative annoyance of combined sound of residential noise and masking sound in equal sound pressure level to the residential noise (annoyance $_{combined}$ − annoyance$_{residential}$); Asterisk statistically indicates significant differences in annoyance ($p < 0.01$).

This is due to the fact that the three masking sounds had high annoyance although their annoyance were high.

3.3. Annoyance of combined sound in various MNRs

Figure 3 shows the relative annoyance of combined sound of residential noise and masking sound in various MNR to the residential noise (annoyance $_{combined}$ − annoyance$_{residential}$) in various MNRs. As shown in Figure 3, in most case annoyance of

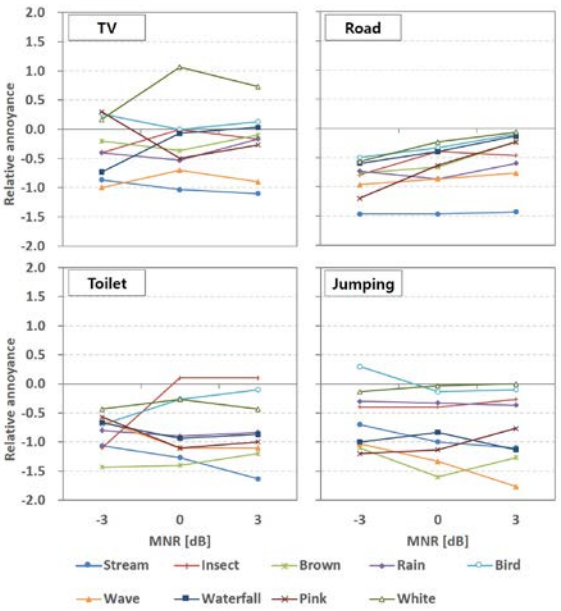

Figure 3. Relative annoyance of combined sound of residential noise and masking sound in various MNRs to the residential noise (annoyance$_{combined}$ − annoyance$_{residential}$)

combined sound in MNR from -3 dB to 3 dB was lower than that of only residential noise. This result indicates that masking sound reduces annoyance of residential noise. Especially, the masking effect was found even if sound pressure level of masking sound is lower than that of residential noise. On the other hands, masking effects of masking sound were not found for several masking sounds such as white noise. With respect to MNRs, there was no tendency of relative annoyance with increasing MNR for all residential noises.

In addition, the masking effect varied with masking sound and residential noise types. Table 2 shows the significant difference of the relative annoyance of combined sound to the only residential noise; Asterisk indicates statistically significant differences in annoyance ($p < 0.01$). As shown in Table 2, it was observed that only stream and wave sound had significant masking effect in all MNR range for all residential noises. Waterfall sound, brown, and pink noise were also effective on masking of toilet and jumping noise in all MNR range. Masking effects of rain sound was also significant in all MNRs for toilet noise. Bird and insect sound were effective on masking of road and traffic noise only in -3 MNR. It was shown that white noise had no masking effect of all residential noise in all MNRs.

Considering relative annoyance with respect to MNRs, all masking sounds except for white noise were effective for road and toilet noise in -3 MNR.

Table II. Significant difference of the relative annoyance of combined sound to the only residential noise; Asterisk indicates statistically significant differences in annoyance ($p < 0.01$).

Masking sound	MNR	Residential noise			
		TV	Road	Toilet	Jump-ing
Stream	–3	*	*	*	*
	0	*	*	*	*
	+3	*	*	*	*
Wave	–3	*	*	*	*
	0	*	*	*	*
	+3	*	*	*	*
Waterfall	–3	*	*	*	*
	0			*	*
	+3			*	*
Rain	–3		*	*	
	0		*	*	
	+3			*	
Bird	–3		*	*	
	0				
	+3				
Insect	–3		*	*	
	0				
	+3				
Brown	–3		*	*	*
	0		*	*	*
	+3			*	*
Pink	–3		*	*	*
	0		*	*	*
	+3			*	*
White	–3				
	0				
	+3				

4. Conclusions

This study investigated the masking effect of artificial and natural sound through auditory experiment. It was found that most masking sounds can reduce annoyance of the residential noise. In addition, the masking effect was observed even when sound level of making sound was -3 dB lower than that of the residential noise. However, the masking effect was strongly dependent on masking and residential sound types. Therefore, further analysis to explain the dependency of the masking effect on masking and residential sound types should be conducted in the future.

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