Effects of indoor and outdoor noise on residents' annoyance and blood pressure

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Summary
This study explored the relationships between responses to indoor and outdoor noises in multi-family housing buildings. In particular, floor impact noise induced by neighbours as well as road traffic and railway noises were considered. Participants were recruited from three different apartment complexes in urban areas of South Korea. Three hundred residents (one hundred from each site) took part in the study. Each participant was asked to respond to a questionnaire survey and measure his/her blood pressure. The questionnaire contained questions about some of their socio-demographic characteristics, noise sensitivity, and annoyance caused by indoor noise (floor impact noise) and outdoor noise (road traffic noise and railway noise). All the participants' blood pressures were measured in order to investigate whether the exposure to the noise have adverse cardiovascular health effects. Some variables such as noise sensitivity were also examined if they have significant influences on the annoyance ratings and blood pressure. It was found that annoyance ratings to both indoor and outdoor noises were associated with blood pressure. Moreover, self-reported noise sensitivity was found to be significantly correlated with the annoyance ratings and blood pressure.

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1. Introduction

Floor impact noise is one of the most annoying indoor noise in multi-family housing buildings [1, 2]. It has been reported that exposure to floor impact noise adversely affects psychological and physical health [3, 4]. A series of scientific investigations have been conducted to examine the effects of exposure to floor impact noise on physiological responses. A recent study has found that exposure to floor impact noise induces significant changes in physiological responses [5]. More precisely, electrodermal activity and respiration rate significantly increased and heart rate decreased after the presentation of floor impact noise stimuli [5]. The physiological changes subsequent to noise exposure indicate that the subjects experienced arousal status due to the noise stimuli [5]. Another laboratory study further investigated the influence of noise sensitivity on the physiological responses and demonstrated clearer changes of physiological responses from the noise sensitive subjects [6]. Although all physiological responses recovered within five minutes of noise exposure, the study established that recovery in the heart rate was slower than other physiological recoveries [6]. However, no attempts were made to investigate the effects of floor impact noise on health on site.
In contrast to building noise, research on environmental noise has demonstrated a significant link between noise exposure and cardiovascular risks [7, 8]. Particularly, it corroborates that noise level and length of noise exposure increase blood pressure [9-11]. Additionally, evidence reveals higher cardiovascular risk among individuals who reported higher noise annoyance [12].
Consequently, the present study examined the relationship between floor impact noise and blood pressure to further determine the potential association between noise exposure and cardiovascular risks. As research on building noise is limited, this study attempted to measure residents' annoyance and blood pressure with the information obtained from respondents on indoor

and outdoor noises at their homes. The study examined the following hypotheses:

- H1: Annoyance of indoor and outdoor noises is associated with changes of blood pressure.
- H2: Annoyance of outdoor noise influences annoyance to indoor noise (vice versa).
- H3: Some other variables (e.g. noise sensitivity) are associated with noise annoyance and blood pressure.

2. Methods

2.1. Sites

Three apartment complexes (Sites A, B, and C) in two satellite cities in South Korea, were selected for the study. The buildings had heavyweight structures and slab thicknesses of 150, 180, and 210 mm, respectively. The Sites A, B, and C were constructed in 1994, 2002, and 2009, respectively, and the number of housing units varied from 262 to 1827. All three sites were located in proximity to a railway track. Measured outdoor noise levels ($L_{\mathrm{Aeq,\,24hr}}$) at three to four building rooftops for 24 hours were 50.6~57 dBA, 54~61 dBA, and 52~64.8 dBA, respectively, for Sites A~C.

2.2. Participants

Three hundred residents (100 from each site) participated in this study. Participants were aged 20 to 60 years old and mean age was 42.8 years old (Std. deviation = 10.47). Since this study involved blood pressure measurements, there were exclusion criteria for the participant recruitment in the following categories.

- Persons below or over the following body mass index (BMI): 18.5 and 25 kg/m^2;
- Persons with cardiovascular, respiratory (e.g. asthma), diabetes mellitus, epilepsy, hearing loss, and musculoskeletal disorders;
- Persons who take any heartbeat-affecting drug;
- Persons with history of smoking, and past experience as a professional athlete.

On arrival, all potential participants were asked to undergo a blood pressure test. Only participants with normal blood pressure that was neither in hypotension or hypertension ranges were allowed to take part in the study. Blood pressure criteria ranged from > 60 and < 90 mm Hg for diastolic blood pressure and > 90 and < 140 mm Hg for systolic blood pressure [13].

Participants' information from each site is listed in Table I. Male and female participants were recruited almost evenly from each site. Most of the participants in the study were employed, with a majority reporting that they were in full-time employment. More than half of participants from Site B reported that they live with one or more children under the age of 12, while more than half from Sites A and C were not living with a child. Length of residency in the current house ranged from 33.7 to 141.1 months across the sites. Sites A and C had the longest and shortest length of residency, respectively, which was partially influenced by the age of building.

Table I. Information of the participants.

		Sites		
		A	B	C
Age (years old)	Mean	44.3	41.6	42.5
	Std. deviation	9.6	11.2	10.5
Gender (%)	Male	46	46	56
	Female	54	54	44
Occupation (%)	Full-time employed	64	54	45
	Part-time employed	14	10	21
	Self-employed	5	5	11
	Student	6	16	9
	Homemaker	11	15	11
	Unemployed	0	0	3
	Other	0	0	0
Child(ren) under 12 years old at home (%)	Yes	30	58	39
	No	70	42	61
Length of residency (months)	Mean	141.1	107.6	59.2
	Std. Deviation	78.3	42.5	29.0

2.3. Questionnaire

Participants were asked to complete the survey questionnaire. The questionnaire included information on participants' socio-demographic characteristics, length of residency, and self-reported noise sensitivity [14]. Furthermore, participants were asked to provide information on major sources of floor impact noise (e.g. child's footsteps) and the time of the noise exposure that they heard the noise mostly. They were also asked to rate the degree of annoyance of individual indoor and outdoor noises (floor impact noise, road traffic noise, and railway noise). In addition, the degree of total annoyance caused by multiple outdoor noises was rated. All annoyance ratings were measured using an 11-point scale (0 = *'not at all'* ~ 10 = *'extremely'*).

2.4. Data analysis

The data were analysed using SPSS for Windows (version 22.0, SPSS Inc. Chicago, IL). In order to compare groups, independent samples t-tests (e.g. difference between low and high noise sensitivity) and one-way analyses of variance (e.g. difference between the three sites) were carried out. Bivariate correlations were tested to examine the relationship between the variables (e.g. association between noise sensitivity and annoyance). In the present study, p values of less than 5% ($p < 0.05$) were considered as statistically significant.

3. Results

Firstly, the study examined the associations between indoor noise annoyance and blood pressure. It was found that annoyance ratings of floor impact noise had significant correlations with both diastolic blood pressure ($r = .723$, $p < 0.01$) and systolic blood pressure ($r = .719$, $p < 0.01$). Furthermore, the participants were classified into low and high floor impact noise annoyance groups (149 and 151 for low and high groups, respectively) and independent-samples *t*-test was then conducted to compare blood pressures across groups. As show in Figure 1, the high annoyance group presented higher diastolic and systolic blood pressures with significant differences between the groups.

Secondly, the association between outdoor noise annoyance and blood pressure was investigated. It was found that outdoor noise annoyance had

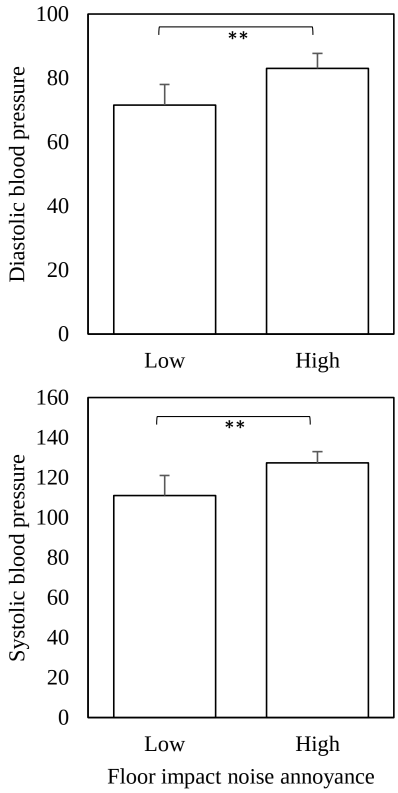

Figure 1. Blood pressure between low and high floor impact noise annoyance groups. * $p < 0.05$, ** $p < 0.01$.

significant correlations with both diastolic blood pressure ($r = .488$, $p < 0.01$) and systolic blood pressure ($r = .438$, $p < 0.01$). Participants were also grouped into low and high total annoyance groups (197 and 103 for low and high groups, respectively) and independent-samples *t*-test was then conducted to compare blood pressures across groups. As show in Figure 2, the high annoyance group exhibited higher diastolic and systolic blood pressures and the differences between the groups were statistically significant.

Thirdly, the relationship between annoyance ratings of indoor noise and outdoor noises was assessed. The annoyance rating of floor impact noise was significantly correlated with the annoyance ratings of road traffic noise ($r = .150$, $p < 0.01$), railway noise ($r = .227$, $p < 0.01$) and total annoyance ($r = .225$, $p < 0.01$); however, the correlation coefficients were relatively small.

In order to explore the impact of other variables on noise annoyance and blood pressure, the present study compared the annoyance rating of floor impact noise across different groups. Figure 3a shows annoyance ratings of floor impact noise across the three sites. It was hypothesised that the

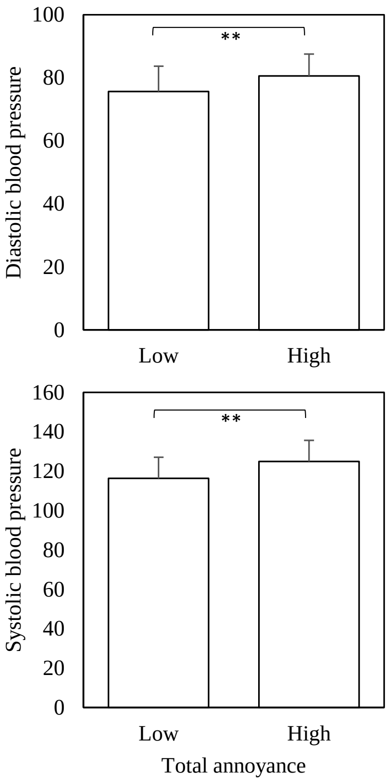

Figure 2. Blood pressure between low and high total annoyance groups. * $p < 0.05$, ** $p < 0.01$.

age of buildings and slab thickness would affect the annoyance ratings of floor impact noise; however, one-way analyses of variance confirmed that there was no significant difference between the sites ($F(2,296) = .834$, $p = .436$). Participants were classified into low and high noise sensitivity groups based on their self-reported noise sensitivity scores. The mean score for the low noise sensitivity group was 66.9 (Std. deviation = 6.56), while the score for the high noise sensitivity group was 93.6 (Std. deviation = 6.76). This study found that the annoyance ratings of floor impact noise for low and high noise sensitivity groups were significantly different (Figure 3b). The high noise sensitivity group displayed higher annoyance ratings than the low noise sensitivity group; mean annoyance ratings were 1.1 and 7.4 for the low and high noise sensitivity groups, respectively. Additionally, noise sensitivity was established to have notable influence on blood pressure. As presented in Figure 4, significantly different diastolic and systolic blood pressures were found between the low and high noise sensitivity groups.

As listed in Table II, children's footsteps were the most dominant source of heavyweight floor

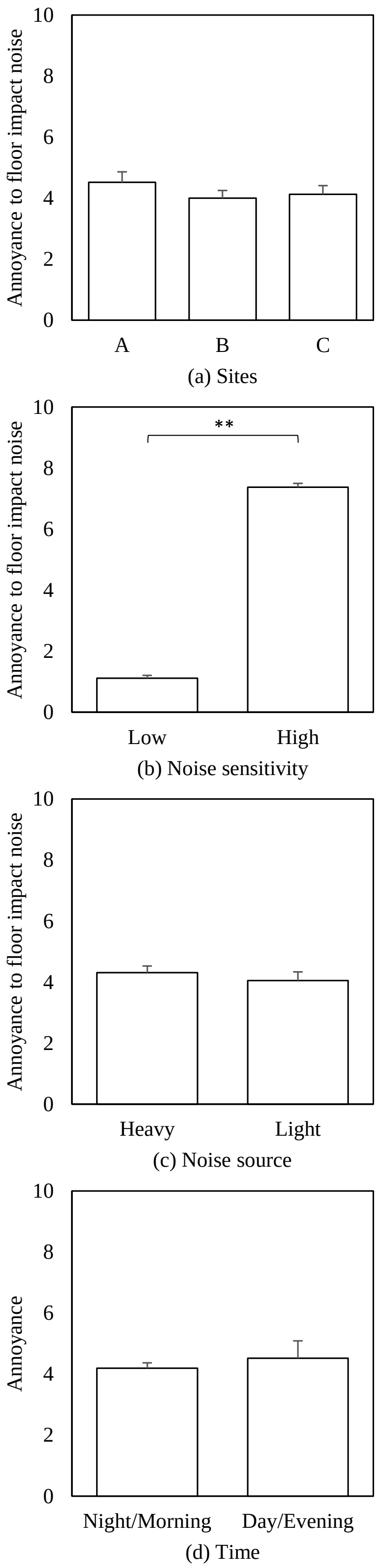

Figure 3. Annoyance to floor impact noise compared between different groups. * $p < 0.05$, ** $p < 0.01$.

impact noise preceding adults' footsteps, and furniture scraping. In addition, night-time (between 20:00 and 06:00) was the most dominant

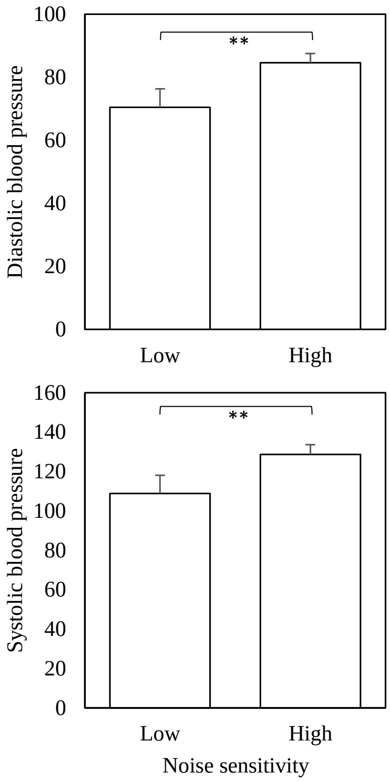

Figure 4. Blood pressure between low and high noise sensitivity groups. * $p < 0.05$, ** $p < 0.01$.

time of noise exposure, which preceded early morning (06:00 to 09:00) and morning (09:00-12:00). Annoyance ratings of floor impact noise were compared across dominant sources of noise (heavy and lightweight impact noise sources) and dominant noise exposure time (night/morning time and day/evening time); nevertheless, no significant difference was found between groups.

4. Discussion

This study validates a significant association between annoyance caused by floor impact noise and blood pressure. This result further expands the previous work on environmental noise which demonstrated a significant relationship between cardiovascular risk and noise annoyance [12]. In addition to previous research findings which reported significant changes in heart rate caused by floor impact noise in laboratory experiments [5, 6], there is an implication that floor impact noise adversely affects cardiovascular health. Moreover, this study substantiates previous evidence between traffic noise and blood pressure [9-12] and corroborates that total annoyance of outdoor traffic noises significantly impacts blood pressure.

Noise sensitivity has been reported as a significant factor that increases annoyance caused by indoor noise including floor impact noise [3, 4, 15]. In line with previous research, the present study also found that noise sensitivity had a significant impact on annoyance ratings of floor impact noise. Furthermore, it was found that noise sensitivity significantly affected blood pressure. This finding is in agreement with an recent laboratory experiment [6], reporting that noise sensitivity has a significant influence on physiological responses (e.g. heart rate) during exposure to floor impact noise and road traffic noise. Noise sensitive people exhibited substantial changes and slower recovery in physiological responses, compared with those with low noise sensitivity.

Table II. Frequency percentages of major noise source and time of noise exposure.

			Percentage [%]			
			Whole	Site A	Site B	Site C
Major noise source	Heavyweight	Child	*40.5*	32.0	53.0	37.0
		Adult	*23.3*	26.0	18.0	26.0
	Lightweight	Furniture scraping	*12.0*	10.0	14.0	12.0
		Items dropping	*12.0*	15.0	10.0	11.0
		Door banging	*7.0*	15.0	0	6.0
		Plumbing	*4.7*	2.0	4.0	8.0
Time of noise exposure	06:00-09:00		*30.2*	41.0	32.0	18.0
	09:00-12:00		*4.0*	3.0	2.0	7.0
	12:00-18:00		*3.3*	4.0	2.0	4.0
	18:00-20:00		*9.0*	10.0	1.0	16.0
	20:00-06:00		*52.8*	42.0	62.0	55.0

The present study found that heavyweight impact sources such as child and adult's footsteps are major sources of noise in apartment buildings. This is also in agreement with previous studies in which heavyweight impacts were dominant sources of floor impact noise [4, 16]. Jeon, Ryu, Jeong and Tachibana [16] reported that footsteps were the most frequent noise source in multi-family housing buildings, particularly those induced by children aged between 6 and 9 years. On the other hand, on-site noise measurements indicated that the actual number of occurrences of heavyweight impact noise was lower than lightweight impact noises [17]. The analysis of 24-hour noise measurements in 26 residences demonstrated that furniture scraping noise (i.e. lightweight impact noise) accounted for 27.8% of total noise incidents, followed by items dropping noise (17.3%), children's running (14.3%), and adults' walking (11.4%) [17]. This implies that the actual number of occurrences of noise incidents does not reflect perceived noise incidents.

Most of the participants in this study reported noise exposure between 20:00 and 09:00, which was in line with a previous qualitative study in which a considerable number of noise complaints were found to be related to night time or early in the morning [4]. However, the on-site noise measurements also showed that the number of noise incidents was the lowest between 23:00 and 07:00. This again implies that residents' activities and background noise level might have affected perceived noise incidents. Firstly, given that night or morning time is likely to be associated with sleeping or resting, the residents may more concentrate on hearing compared with daytime. Consequently, they may exhibit stronger annoyance to the noise incidents that disturb their sleeping or resting [3, 4, 17]. Secondly, relatively low outdoor noise during this time may contribute to a higher signal-to-noise ratio than at other times of the day; thus, the residents may hear clearer incidents of floor impact noise. However, contrary to existing research on environmental noise [18, 19], evidence of the influence of background noise on indoor noise annoyance is still limited. Hence, future research should explore the association between ambient noise levels, annoyance, and blood pressure.

5. Conclusions

The present study aimed to investigate relationships between indoor and outdoor noise annoyance and blood pressure. In addition, this study explored additional significant factors which have impacts on the annoyance ratings and blood pressure. A total of 300 residents from three apartment complexes in South Korea participated in this study. This study employed survey questionnaires and requested the participants to rate their degree of annoyance perceived by individual indoor and outdoor noises; in particular, they were floor impact noise, road traffic noise, and railway noise. The participants were also asked to rate their total annoyance caused by multiple outdoor noises. Before and after the survey, their blood pressures were measured in order to examine their physiological reactions to noise. It was found that blood pressure was significantly associated with annoyance caused by not only floor impact noise but also all outdoor noises. Furthermore, it was found that noise sensitivity significantly correlated with the annoyance ratings and blood pressure. Although each of the sites had different slab thicknesses, it was found that floor impact noise annoyance was not significantly different between the sites. In addition, type of major noise source and time of noise exposure did not have any significant links with annoyance and blood pressure.

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