PSYCHOLOGICAL AND PHYSIOLOGICAL RESPONSES TO FLOOR IMPACT NOISE

Thesis submitted in accordance with the requirements of
the University of Liverpool for the degree of Doctor of Philosophy
by
Sang Hee Park

Acoustics Research Unit
School of Architecture
School of the Arts
Faculty of Humanities and Social Sciences
University of Liverpool

December 2018

Psychological and physiological responses to floor impact noise

Sang Hee Park

This research investigated psychological and physiological responses to floor impact noise. It consists of six studies. The first study carried out 24-hour noise measurements inside real residences in multi-family housing buildings. Different airborne and structure-borne noise sources, and their characteristics (e.g. noise level) were identified. Slab thickness did not have any correlation with the noise characteristics. It implies that although the slab thickness is an important factor, other physical characteristics and upstairs neighbours' activities are also important determinants. The second and third studies measured psychological and physiological responses to floor impact noise in laboratory settings. Real and standard impact noise sources (e.g. human footsteps and the impact ball) were used as stimuli. Noticeability and annoyance increased as the noise level increased. There were significant differences between real and standard impact noise exposure in the noticeability and annoyance. The noise exposure also changed the physiological responses. In addition, self-reported noise sensitivity had significant impacts on the responses; greater responses were shown by the high noise-sensitivity group. The fourth study investigated emotions evoked by the floor impact noise. Emotion lexicons were collected from previous interview transcripts and online postings. The lexicons were then sampled and clustered into grouped through survey studies. Four emotion clusters (anger, dislike, pain, and empathy) were examined in a laboratory study when the noise stimuli were presented. The results showed that the emotions had strong correlations with the noise level and annoyance. Noise sensitivity and attitude towards neighbours showed significant influences on the responses. The fifth study tested those found so far in the previous chapters. Their psychological responses to indoor noise (e.g. annoyance) were found to be influenced by various factors (e.g. noise sensitivity). Outdoor noise level did not have any masking effect on the indoor noise responses. In addition, the psychological responses to indoor noise had significant effects on blood pressure and health-related quality of life. The sixth study investigated the relationship between residents' attitudes towards neighbours and their coping strategies. Of many conditions which may influence their attitudes and copings, the chapter particularly highlights three conditions: attitudes shown by the neighbours, past experience/history, and predictability/uncertainty.

Acknowledgement

First of all, I would like to express my deepest appreciation to my supervisors, Dr Pyoung Jik Lee and Professor Carl Hopkins for their guidance, encouragement, and support.

Besides, I am very grateful to my thesis committee, Professor Jian Kang and Professor Barry Gibbs, for their insightful comments and suggestions for this thesis.

I express my deep gratitude to Dr Gary Seiffert and Dr Jeong Ho Jeong. This research would not have been possible without their willingness to give their time so generously.

Moreover, my sincere thanks must go to all of those who participated in my experiments, surveys, and interviews. In addition, special thanks to all the anonymous reviewers who kindly gave invaluable comments on the articles included in some of the chapters in this thesis.

I gratefully acknowledge the financial support of the Korea Institute of Construction Technology and the Korean Ministry of Land, Infrastructure and Transport.

I would like to thank all of my friends for their warm support and prayer. I would also like to thank every single person in the Acoustics Research Unit for their encouragement and friendship.

Last but not least, I extend my deepest gratitude to my husband, Seongwon, and my whole family for their endless support, prayer, and love.

Table of contents

List of tables

List of figures

List of abbreviations

ANOVA	Analysis of variance
B	Unstandardised regression
β	Standardised beta: regression coefficient
df	Degrees of freedom
F	F-statistic: a ratio of two quantities
L_{AE}, SEL	A-weighted sound exposure levels
L_{Aeq}	A-weighted equivalent continuous sound level
L_{AFmax}	A-weighted maximum level with the Fast time constant
L_{den}, $DENL$	Day-evening-night sound level
L_{dn}, DNL	Day-night sound level
M	Mean
Max	Maximum
Mdn	Median
Min	Minimum
N	Sample number
n	Subsample number
p	Probability
R, r	Coefficient of correlation
R^2	R-squared: coefficient of multiple determination
SD	Standard deviation
SE	Standard error
WHO	World Health Organization

1 Introduction

1.1 Research background

The distinction between noise and sound has long been made. Sound is a change in air pressure that is detected by the ear, whereas noise is a psychological concept and is defined as sound that is unwanted by the listener (Cohen and Weinstein, 1981). In other words, sound can be perceived as noise if the listener perceives it as unpleasant or physiologically harmful, or recognises it disturbs activities (Cohen and Weinstein, 1981). Environmental noise includes noises made by various noise sources such as transportation, machinery, and neighbours (Berglund and Lindvall, 1995). Research on environmental noise has proposed that noise is a threat to public health and well-being. Noise not only causes auditory health problems such as hearing impairment and hearing loss but also causes various non-auditory risks on health and well-being. For instance, transportation noise has been known to have adverse psychological effects such as annoyance (e.g. Öhrström et al., 1980; Ouis, 2001) and risks on physical health such as heart trouble (e.g. Parrot et al., 1992; Babisch, 2008). The adverse noise effects have been assessed with diverse research methods including social surveys and laboratory experiments (e.g. Öhrström and Rylander, 1982; Fyhri and Aasvang, 2010). Moreover, studies on transportation or machinery noises have carried out long-term noise measurements (e.g. for 24 hours) in order to evaluate the effects of noise on human (e.g. Miedema and Vos, 1998; Miedema and Vos, 2004). On the other hand, there is a lack of such noise measurements which can examine what kinds of indoor noise events residents are exposed to in their daily lives, particularly in multi-family housing buildings. There is also a lack of evidence explaining the adverse effects of neighbour noise, particularly of floor impact noise.

Multi-family housing is one of the dominant housing types in many countries. For example, one in seven (14%) would live in a flat or maisonette in the UK (Atkin, 2017). Multi-family housing is more dominant in several countries. In particular, Statistics Korea (2017) reported that such type of housing with reinforced concrete structure accounted for over 60.1 % of the whole housing units. Residents in this type of buildings are easily exposed to numerous noises from their neighbours which lead to a large number of noise complaints (Jeon et al., 2015). One of the ways to reduce the level of noise from upstairs is to increase slab thickness. Slab thicknesses of the buildings mostly ranged from 120 to 180 mm before 2005 without any legal regulation, but the Korean Government has strengthened the domestic regulation to increase the concrete slab thicknesses (Ministry of Construction and Transportation, 2005). The current law clearly states that the concrete slab should be 210 mm or thicker (Ministry of Land, Infrastructure and Transport, 2018). It has been empirically proven that the impact sound insulation of the floors improves with the increased concrete slab thickness. Jeon et al. (2006b) examined the effects of the structural stiffness of concrete slabs on the floor impact noise produced by the heavy-weight impact source by the field measurement and the FEM (Finite Element Modelling). They tested the concrete thickness ranging from 150 to 240 mm. The results showed that every 30 mm increment of concrete slab decreased 2 dB of the floor impact sound pressure level ($L_{i,\mathrm{Fmax,AW}}$).

This can be supported by the mass law theory of the effect of increment in slab thickness on the sound insulation (Hopkins, 2007). The transmission loss in decibels for normal incident non-resonant transmission ($R_{\mathrm{NR},0°}$) gives the following equation. Using the equation, the increment of thickness from 180 mm to 210 mm leads to 1.3 dB difference.

$$R_{\mathrm{NR},0^\circ} = 10\lg\left(1 + \left(\frac{\omega\rho_s}{2\rho_0 c_0}\right)^2\right)$$

where ω is angular frequency or velocity (radians/s), ρ_s is mass per unit area/surface density (kg/m^2), ρ_0 is density of air (kg/m^3), and c_0 is phase velocity of sound in air (m/s).

However, the number of noise complaints regarding neighbour noise has still increased. The number of complaints about neighbour noise registered to the Ministry of Environment of South Korea doubled from 2005 to 2010 (Cha and Ko, 2013). Given that most of the complaints could have also been raised from residents living in old buildings with thinner slabs which were built before 2005, it is still unknown whether or not the increased slab thickness is effective in reducing the indoor noise level in the real residential buildings. In addition, the Korean Government started operating the Floor Noise Management Centre from 2012 in order to particularly deal with noise complaints regarding neighbour noise. The public can register noise complaints and apply for on-site noise measurements if needed. The Floor Noise Management Centre publishes monthly reports showing statistics of the noise complaints and on-site noise measurements. According to the recent report published in May 2018, there were more than one hundred thousands of noise complaints registered between its establishment in 2012 and end of May 2018 (Table 1-1). The report addressed that 28.5 % of the complainants applied for the on-site noise measurements. Of the completed on-site noise measurements, 82.6 % were due to floor impact noise which footstep noise accounted for 70.9 %. Most of the complainants were residents in multi-family housing buildings but there is a lack of investigation whether each house's slab thickness correlated with the noise exposure. It was also reported that many of the complainants had experienced disputes and conflicts with their neighbours because of the noise (Floor Noise Management Centre, 2018). Furthermore, there were four murder cases caused by neighbour noise only in 2013 (Park, 2015a).

Table 1-1. The number of noise complaints and on-site noise measurements in each year from 2012 to 2017 (Floor Noise Management Centre, 2018).

	Number of noise complaints			Number of on-site noise measurements	
Year	Sum	Phone-calls	Online	Applied	Completed
2012	8,795	7,021	1,774	1,829	728
2013	18,524	15,455	3,069	3,271	2,620
2014	20,641	16,370	4,271	4,465	4,617
2015	19,278	15,619	3,659	4,712	5,000
2016	19,495	14,204	5,291	6,306	5,741
2017	22,849	14,828	8,021	9,225	8,667

The author's previous thesis suggested that the exposure to floor impact noise associated with annoyance, disturbance, and health complaints which are affected by several non-acoustic factors (Park, 2015b). However, the works in the previous thesis only involved self-reported data collected from the interviews and questionnaire surveys so there is a need for further validation through objective examinations such as noise measurements and physiological measurements. This work, therefore, aimed to investigate noise events exposed in real residences and the adverse effects of the noise on health and well-being. Moreover, unlike research on other environmental noises in which actual noise sources (e.g. aircraft or trains) can be used as stimuli in laboratory experiments, research on floor impact noise has used standard heavyweight impact noise sources such as bang machines, tapping machines, and impact balls instead of human-generated noises (e.g. JIS A 1418-2; KS F 2810-2; ISO 10140-3; ISO 16283-2). Of the standard sources, it has been suggested that the noise made by the impact ball is similar to that of humans such as children's running and jumping (Jeon et al., 2006a; Jeon et al., 2009b). Therefore, the impact ball has frequently been used in research on sound transmission and insulation (e.g. Hopkins, 2015; Park et al., 2015; Robinson and Hopkins, 2015) and subjective evaluation to the noise (e.g. Jeon et al., 2009a; Lee et al., 2009). In particular, Jeon et al. (2009a) reported that self-reported annoyance rated to the impact ball noise stimuli increased as the sound pressure levels increased. Lee et al.

(2009) found annoyance rated to the impact ball noise stimuli showed strong correlations with sound quality (SQ) metrics such as loudness. However, the impact ball cannot be used to replicate all different kinds of noise made by humans even though the noise of an impact ball has been known to have similar characteristics to that of humans. Given that there is a lack of research that adopted real floor impact noise and measured responses to the real noises, this study aimed to fill the gap by investigating real floor impact noise through various research approaches. There is also a need for comparative investigations into human responses caused by both real and standard impact noises so that the previous studies in which the standard impact sources were used can be validated.

1.2 Research questions

This research focuses on human response to floor impact noise, which is one of many neighbour noises and which has been considered as one of the critical social issues in many countries. The whole research aimed to answer the following three research questions.

- What kinds of indoor noise would be heard in real residences in heavyweight multi-family housing buildings?
- How do people respond to floor impact noise psychologically and physiologically?
- What factors have effects on the responses to floor impact noise?

1.3 Outline of the thesis

This research work consists of six studies. The studies were conducted with various research methods to find answers to the research questions (Figure 1-1). As Rice (1996) noted the advantages and disadvantages of different research methods, laboratory studies were carried out to conduct repeated measures designs, to isolate and combine noises, and to control accurate physical parameter. However, this method can only be conducted in the simulated listening facility, examines relative projected annoyance responses, presents noises for short lengths, and the availability of participant groups are limited. The method of social surveys gives researchers opportunities to investigate the real-life situation, long-term noise exposure, and annoyance actually experienced by the participants with absolute judgments. However, this method cannot control the combined noise exposure and needs a lot of time and financial budget to conduct (Rice, 1996). Therefore, different research methods were used in this research in order to supplement the gaps from one another. The research objectives are expanded and explored progressively according to the following chapter structures.

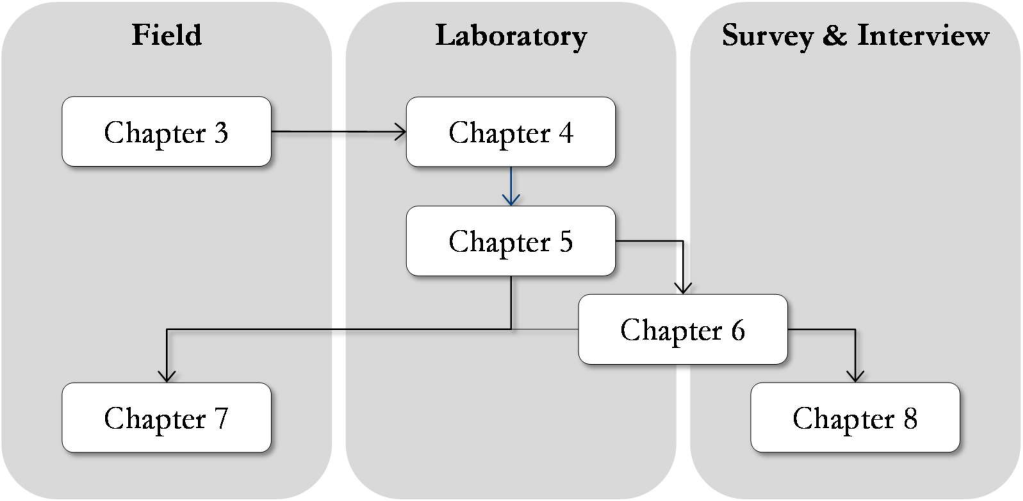


Figure 1-1. Outline of the six studies using different research methods.

Chapter 2: Literature review The literature review in Chapter 2 explores the background and existing literature related to the research topics of this study. The chapter starts with the brief introduction of environmental stress theories. Regarding noise as one of the environmental stressors, the chapter continues reviewing the existing studies on different responses to noise. It introduces noticeability and annoyance as the major responses to noise or acoustic stimuli. Diverse acoustic and non-acoustic factors are described to have impacts on the prevalence of annoyance. The chapter then reviews studies which examined emotions using lexicons since noise annoyance is closely related to various emotions. It then continues reviewing studies which measured physiological responses to noise or acoustic stimuli.

Chapter 3: Characteristics of noise events caused by upstairs neighbours in multi-family housing: Field measurements This chapter illustrates a field study in which on-site noise measurements were carried out in real residences of multi-family housing buildings for 24 hours. The study aimed to investigate actual indoor noise events. The occupants of the sites vacated their houses while the measurements were being conducted. The study measured the overall noise levels (L_{Aeq} and L_{AFmax}) for 24 hours and the noise levels were compared between different time periods (day, evening, and night). It also identified the noise source of each noise event which exceeded the threshold noise levels (e.g. L_{Aeq} of 35 dBA for daytime). Moreover, it investigated noise level, noise length, and the number of occurrence of each noise source. Since the participated sites used different thicknesses of slabs, the study investigated if there was any effect of slab thickness on the noise level. The chapter suggests that there is a need for assessing subjective responses of the occupants living in the residences.

Chapter 4: Psychological and physiological responses to floor impact noise: A laboratory study This chapter presents a laboratory study which assessed psychological and physiological responses to floor impact noise stimuli. Self-reported noticeability and annoyance were assessed as psychological responses. Three different physiological responses were measured while the stimuli were presented; they were heart rate, electrodermal activity, and respiration rate. The noise stimuli included different floor impact noises. For instance, human footsteps and a scraping noise of a chair were used as the real impact noise stimuli and the impact ball noise was used as the standard impact noise stimuli. The noise stimuli lasted for 23 seconds each. The stimuli were presented at different noise levels, ranging from 31.5 to 63 dBA (L_{AFmax}). The study examined the impacts of the noise level and the type of noise source on the responses. This chapter proposes that there is a need for investigating the effects of longer noise stimuli and non-acoustic factors (e.g. noise sensitivity) on the responses.

Chapter 5: Effects of noise sensitivity on psychological and physiological responses to floor impact noise: A laboratory study This chapter shows another laboratory study in which psychological and physiological responses to floor impact noise stimuli were evaluated. Self-reported annoyance was assessed as the psychological response and the three physiological responses (heart rate, electrodermal activity, and respiration rate) were monitored throughout the stimuli presentations. Length of the stimuli was designed to last for 5 minutes which was longer than the stimuli used in the previous experiment (Chapter 4) in order to investigate the influence of the duration of the noise exposure. The noise stimuli included floor impact noises generated by human footsteps and the impact ball. They were played at 40, 50, and 60 dBA (L_{AFmax}). In addition, road traffic noise was also used as another noise stimulus. It was presented at 40 and 60 dBA (L_{Aeq}). The impacts of the noise level and the type of noise source on the responses were assessed. In addition, the participants were grouped into low and high noise-sensitivity groups in order to assess the effect of noise sensitivity on the responses.

Based on the findings from the study, the chapter discusses that future research may evaluate emotions evoked by the noise in order to further understand the subjective responses to the noise.

Chapter 6: Emotions evoked by floor impact noise: Survey and laboratory studies This chapter describes a study which involved questionnaire surveys and laboratory experiments. It aimed to explore different emotions evoked by floor impact noise. Human footstep noise was used as the noise stimulus in the surveys. First, lexicons expressing emotions evoked by the exposure to neighbours' floor impact noise (e.g. footstep noise) were collected. Second, two online surveys were carried out in order to sample the lexicons and cluster them into groups. Based on the responses collected from the surveys, different emotion lexicons were classified into four clusters representing the major emotions evoked by the noise. Third, the laboratory study was conducted to test the four emotion clusters when the floor impact noise stimuli were played at different noise levels ranging from 30 to 60 dBA (L_{AFmax}). Self-reported annoyance was also measured in order to assess its relationship with the emotions. The study explored the effects of the noise level, self-reported noise sensitivity, and attitude towards neighbours (i.e. noise source) on the responses. Since the results showed less significant impacts of the attitude compared to those of noise sensitivity, the chapter proposes that there is a need for further examination into the attitude towards neighbours.

Chapter 7: Psychological responses to indoor noise and its relationship with various factors: A field study This chapter illustrates a field study which examined the effects of various factors on residents' psychological responses to floor impact noise. The study assessed the relationships between residents' psychological responses to floor impact noise (self-reported annoyance and emotions), satisfaction with indoor noise, diverse personal factors (e.g. socio-demographic characteristics), characteristics of the house (e.g. slab thickness), characteristics of floor impact noise exposure (e.g. major noise source), and outdoor noise (e.g.

outdoor noise level or road traffic noise annoyance). In particular, outdoor noise levels were measured for 24 hours on top of buildings and the noise maps were computed in order to predict the outdoor noise levels exposed to each house in which each participant lived. Moreover, it investigated whether the psychological responses to floor impact noise had any potential adverse health effects by measuring the self-reported quality of life and blood pressure. The chapter suggests future research may carry out both the indoor noise measurements and subjective evaluation of the noise of the occupants.

Chapter 8: Attitudes to neighbours and coping with their noise: A qualitative study This chapter shows a qualitative study which focused on exploring psychological mechanisms between residents' attitudes towards their neighbours who were the major noise source and how they coped with the noise. In-depth interviews were conducted with residents in multi-family housing utilising the grounded theory methods. The study investigated what factors influenced individuals' attitudes towards their neighbours to be formed. Of various factors which were found to have influences, the chapter particularly introduces certain factors which were dominantly observed in the interviews. The chapter also discussed how different attitudes may lead to different coping strategies. The chapter concludes by making suggestions that future research may investigate what factors have impacts on the individuals' coping strategies.

Chapter 9: Conclusion This chapter summarises the major findings and contributions of each part of this thesis. Adopting one of the diagrams of the stress model introduced in the literature review, the chapter recapitulates the findings from each chapter in the diagram. The chapter concludes by discussing the limitations of the scope and methods of the research, and corresponding potential works in the future.

Most of the studies in this research work involved human participants (Chapters 4 ~ 8). Approvals for the studies were obtained from the Ethical Committee of the School of the Arts, University of Liverpool. All data used in the research were collected in a manner consistent with ethical standards for the treatment of human participants. Chapters 3 ~ 6 have been partially published in peer-reviewed journals. Chapters 3 ~ 7 have been partially published in conference proceedings. In addition, Chapters 7 and 8 are currently under review in peer-reviewed journals. Table 1-2 summarises in which setting each study was conducted and what variables were mainly examined.

Table 1-2. Details of each study in Chapters 3 ~ 8.

Chapter	Setting	Measurements	Noise source
3	Field *N* = 32 sites	▪ Noise source ▪ Noise level ▪ Noise length ▪ Number of occurrence	▪ Real neighbour noise
4	Laboratory *N* = 21	▪ Dependent variables: - Noticeability - Annoyance - Heart rate - Electrodermal activity - Respiration rate ▪ Independent variables: - Noise level - Noise source	▪ Real floor impact noise (e.g. human footsteps, a small object dropping, etc.) ▪ Standard floor impact noise (impact ball)
5	Laboratory *N* = 34	▪ Dependent variables: - Annoyance - Heart rate - Electrodermal activity - Respiration rate ▪ Independent variables: - Noise level - Noise source - Self-reported noise sensitivity	▪ Real floor impact noise (human footsteps) ▪ Standard floor impact noise (impact ball) ▪ Road traffic noise
6	Survey *N* = 133; 89 Laboratory *N* = 41	▪ Dependent variables: - Annoyance - Emotion ▪ Independent variables: - Noise level - Self-reported noise sensitivity ▪ Attitude towards neighbours	▪ Real floor impact noise (human footsteps)
7	Field *N* = 400	▪ Dependent variables: - Perceptions of floor impact noise - Satisfaction with indoor noise environment - Health consequences (self-reported quality of life; blood pressure) ▪ Independent variables: - Personal factors - House characteristics - Floor impact noise characteristics - Outdoor noise characteristics - Perceptions of the outdoor noise	▪ Real floor impact noise ▪ Outdoor noise
8	Interview *N* = 57	▪ Attitude towards neighbours ▪ Coping strategy ▪ Acoustic and non-acoustic conditions	▪ Real neighbour noise

2 Literature review

2.1 Introduction

As part of the research on the effects of floor impact noise on people, the literature review gives general ideas of the current state of the relevant research fields. The existing models for understanding environmental stress are briefly reviewed in the following section (Subchapter 2.2). It first introduces the traditional model of stress theory. It then presents the environmental stress model which were developed based on the traditional model. Since noise is one of the environmental stressors, Subchapter 2.3 then reviews various responses to noise which have been observed in previous studies. This section particularly reviews the studies on noticeability, annoyance, emotion, and physiological responses to noise or acoustic stimuli. Furthermore, the section introduces several acoustic and non-acoustic factors which had significant impacts on the responses.

2.2 Environmental stress

Stress is the term which can be traced back to the time when Selye (1936) first discovered and proposed the idea of the general adaptation syndrome (Selye, 1936, 1956). Stress as a process in which stressors threaten an organism's existence and well-being (Baum et al., 1982). Stress response is the body's effort in order to maintain or restore homeostasis (Goldstein and Kopin, 2007). In the stress response, cognitive appraisal phases have been known to play significant roles since Lazarus (1966) proposed the idea (Figure 2-1). The idea of appraisals refers to the phases in which individuals appraise whether the stressor may lead to potential harm (primary appraisal) and what they can do to reduce the tension that the stressor may bring (secondary appraisal). To put it another way, the environment may be perceived as a stressor in the primary phase and the individual's psychological and cognitive resources are appraised in the secondary phase (Lazarus, 1966).

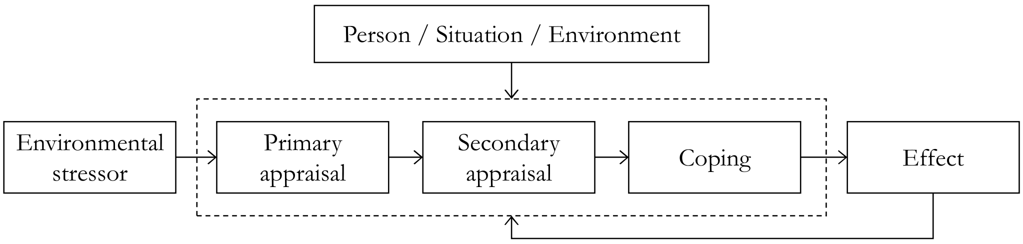


Figure 2-1. The theoretical model of stress (Lazarus and Folkman, 1984).

Bell et al. (1990) later suggested a theoretical model of environmental stress (Figure 2-2) based on the existing perspectives on stress. This model mainly focuses on describing whether each environment is perceived as stressor or not and whether each coping is successful or not. The model first illustrates that objective physical conditions associate with various factors. Bell et al. (1990) introduced variables such as population density, temperature, and noise level as the objective conditions. The objective conditions interact with individual differences such as length of exposure and personality. Situational, social, and cultural factors include liking/hostility for others in the situation, attraction of the environments, and housing design. The model describes that the perception of the environment is influenced by both objective and individual variables. The perception results in arousal, stress, or reactance when the environment is perceived as outside an optimal range of stimulation. Stress reaction includes not only emotional symptoms such as fear, anxiety, and anger but also behavioural and physiological components. Coping then follows after the arousal, stress, and reactance. Coping leads to different consequences depending on whether or not the coping is successful. The consequences are likely to again affect the individual differences and perception of the environment; Lazarus (1966) earlier called this phase as the reappraisal.

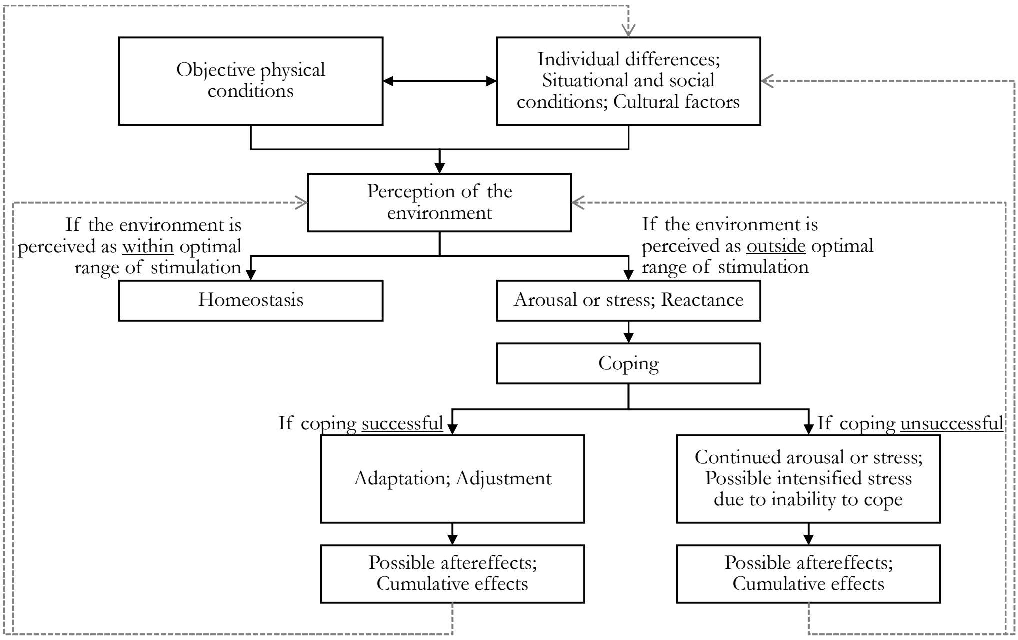


Figure 2-2. The theoretical model of environmental stress (Bell et al., 1990).

2.3 Noise as an environmental stressor

As one of the environmental stressors, noise has adverse and threatening influences on human well-being (Bell et al., 1990; van Kamp, 1990; Berglund et al., 1999; Bronzaft, 2002). As one of the environmental stressors, noise response can be explained based on the stress models of Lazarus and Bell et al. (Figures 2-1 and 2-2). Figure 2-3 is constructed to present the noise and its relationship with other variables. When noise is noticed (i.e. noise perception), the noise exposure is subjectively judged in the phase of primary appraisal. Then the individual's psychological and cognitive resources are evaluated in the phase of secondary appraisal (Lazarus, 1966; van Kamp, 1990; Lercher, 1996). Once the noise is appraised as annoying, emotional reactions and physiological responses are evoked. This section reviews existing literature on a wide range of studies on environmental noise to understand the response to noise as an environmental stressor.

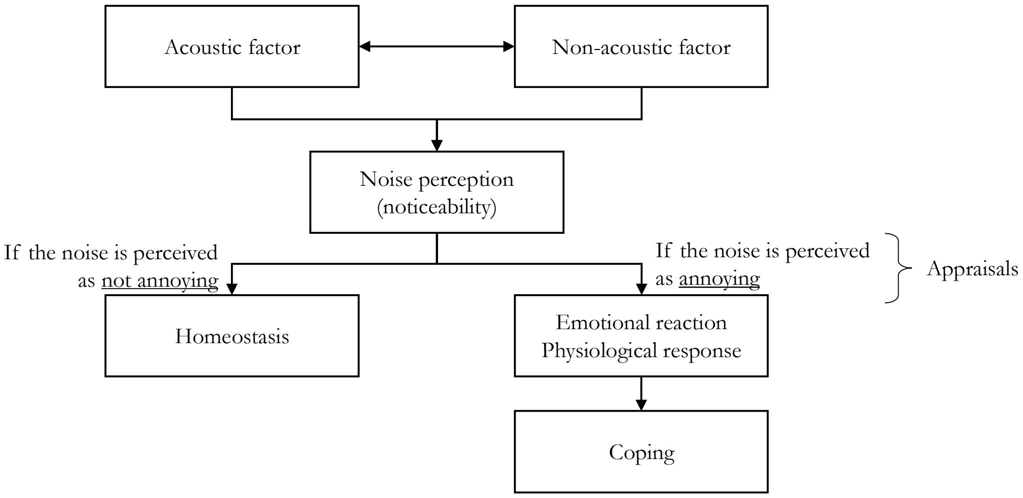


Figure 2-3. A model illustrating noise as an environmental stressor.

2.3.1 Noticeability and annoyance

Fidell et al. (1979) earlier investigated the relationship between noticeability and annoyance in a laboratory study. They used 24 sound clips of which levels varied from 48.4 to 63.9 dBA. Sources of the stimuli included a transformer, a hair dryer, an air compressor, a vacuum cleaner, a garbage compactor, a train, a motorcycle, an automobile, etc. The stimuli were presented in three different background sounds which were played at 50 dBA. The background sounds included a falling spectrum resembling everyday ambient noise environments (PNC-40), a flat spectrum, and a rising spectrum. Their participants (*N* = 30) were asked to push a button to the more annoying stimulus when a pair was presented. The results showed that noticeability and annoyance had a positive correlation. The rising background noise decreased the correlation between noticeability and annoyance. In addition, individuals' variances were suggested to have impacts on the annoyance rating. Schomer and Wagner (1996) later carried out on-site measurements in participants' dwellings (*N* = 25). First, three test sites where different noises were mainly exposed were chosen. Major noise sources included military jet aircraft, commercial jet aircraft, helicopters, small propeller aircraft, and trains. Then, residents in each site were recruited and they rated noticeability and annoyance using palm-top computers. Outdoor noise recordings were conducted from 07:00 to 22:00 and the noise recordings were later matched with the participants' responses. Noticeability and sound exposure level had a positive correlation. The strongest and weakest correlations were found from helicopter and commercial jet aircraft noises, respectively. Besides, noticeability also had a positive correlation with annoyance. In a more recent study, Sneddon et al. (2003) carried out a laboratory study and tested detectability of the stimuli when the participants (*N* = 10) were reading some materials (e.g. newspapers or magazines). They used five noise stimuli including a passenger aircraft landing, a military aircraft fly-over, a truck drive-by, a mid-sized automobile drive-by, and a passenger train pass-by. The stimuli lasted between 20 and 30 seconds each and were presented at four different levels. The stimuli were played in three different background sounds: an urban sound (recognizable street and traffic), a sound containing voice (indistinct babble), and a sound of the rural area (distinct birdsong and running water). The participants were asked to click an icon on the screen using a mouse when they noticed a sound. Annoyance to each stimulus was asked at the end of the detected stimuli. The results showed that the percentage of missing the stimuli and detectability had a negative correlation. Annoyance had a positive correlation with detectability. The urban background noise affected the participants to wrongly respond the detectability the most among the three background sounds.

Annoyance is one of the major non-auditory effects of noise. Unwanted intensity, frequency, intermittency, excessive loudness, or startle can make sounds to be perceived as noise and as annoying (Cohen and Weinstein, 1981). A number of studies have found various acoustic factors which have impacts on noise annoyance. Rylander et al. (1980) carried out social surveys in order to investigate the relationship between aircraft noise exposure and self-reported annoyance. The study was carried out in 38 areas around nine airports. The focused areas were around one airport in Norway, two airports in Denmark, and six airports in Sweden. Survey responses were collected from a total of 3,746 residents in the areas. The results showed that the increased number of aircraft increased the extent of annoyance but only up to a certain number. In addition, the extent of "very annoyed" was low when the noise level did not exceed 70 dBA even if the number of overflights was large. Not only do the number of noise events and the noise level influence annoyance, but also different types of noise sources or frequency characteristics have impacts on annoyance. Versfeld and Vos (1997) later conducted a laboratory study in which the relationship between annoyance and noise exposure generated by the different type of vehicles. They recorded noises of a tracked main battle, a tracked armoured personnel carrier, a wheeled 4-ton truck, and a four-wheel drive car from 50, 100, 200, and 400 m distances. They also carried out noise recordings of civil road traffic from 12.5, 25, 50, and 100 m from the centre of a two-lane road. The traffic consisted of two passenger cars, a delivery van, a bus, and a truck with a trailer. The participants ($N = 20$) rated annoyance to each stimulus. It was found that the noise level increased annoyance ratings. In particular, when L_{AE} were below 55 dBA, the passenger cars were rated as more annoying than the heavier wheeled vehicles such as the bus or the truck with a trailer. It implied the difference between the high-frequency and the low-frequency parts of the spectrum had an impact on the response. Of the acoustic factors, Kurra et al. (1999) highlighted the significant impact of noise level on annoyance. They conducted a laboratory study in order to assess subjective annoyance rated to transportation noise stimuli. The participants ($N = 64$) were presented with three different sessions which lasted for 30 minutes each. Noise sources included road, railway, and aircraft traffic noises and the noise levels ranged from 30 to 55 dBA with 5 dB intervals. In particular, the aircraft and railway noises were comprised of 8, 12, and 16 pass-bys, while the road traffic noise was continuous. The results showed that annoyance closely related to the noise level more than the source type. Additionally, they suggested that the indoor noise level of 45 dBA caused neutral annoyance response.

Studies on indoor noise have also suggested diverse acoustic factors affecting annoyance. Langdon et al. (1981) earlier carried out a survey study in order to assess how the sound insulation of walls in houses influenced the occupants' responses to neighbour noise. The respondents (*N* = 917) reported nuisance response due to airborne noises. Neighbour noise sources included noises of television, shouting, banging doors, footsteps on stairs, plumbing, vacuum cleaner, etc. They also found that impact noise contributed to nuisance particularly when airborne sound insulation was comparatively good. More recently, annoyance evoked by the indoor impact noise has been studied. Jeon et al. (2004) emphasised the impact of noise level on the prevalence of annoyance. They conducted a laboratory study in order to determine the appropriate sound isolation treatment in reinforced concrete structures. The participants (*N* = 30) were presented with the noise stimuli generated by either the tapping machine or the bang machine. The results showed that self-reported loudness and annoyance decreased with the isolation of retaining walls along with the floating floors. Jeon et al. (2009a) later carried out another laboratory study in order to examine annoyance response caused by heavyweight floor impact noise. The participants (*N* = 20) were exposed to nine noise stimuli which were generated by the impact ball and lasted for 7 seconds each. They reported that annoyance was affected by sound pressure levels and interaural cross-correlation. In order to cover a wider range of neighbour noise including impact and airborne noises, Jeon et al. (2010b) investigated annoyance and dissatisfaction evoked by various neighbour noises. They first carried out social surveys with residents living in multi-family housing buildings in South Korea (*N* = 512). The noises of children's jumping and running were the most annoyance-evoking floor impact noise sources. Musical instrument and people talking were found to be the most annoying airborne noise sources. They then conducted a laboratory study using the noise sources which were rated as annoying in the prior survey study. The participants (*N* = 109) were exposed to the noise stimuli of a child jumping, a bathtub draining, a flushing toilet exposed from upstairs, conversation and piano sounds from next door, and road traffic noise coming from outside. It was reported that the noise level increased annoyance ratings. Given that the noise level has been known to have significant impacts on noise annoyance, Ryu et al. (2011) examined various single-number quantities to predict annoyance responses to heavyweight floor impact noise in wooden houses. They carried out laboratory experiments in which annoyance responses were measured. The noise stimuli were generated by a bang machine and the impact ball recorded in 12 wooden houses with different floors. In the first experiment, the participants ($N = 17$) were presented with the stimuli at five different noise levels ranging from 45 to 65 dBA with 5 dB intervals. In the second experiment, the participants ($N = 31$) were exposed to the noise stimuli at 55 and 65 dBA with different insulations either in the higher or lower frequency ranges. The results showed that the arithmetic average ($L_{\mathrm{iFavg,Fmax}}$) of octave-band sound pressure levels and Zwicker's percentile loudness (N5) predicted the annoyance well over the wide range of noise levels.

It has long been known that individuals' subjective responses to noise are so diverse and they cannot be fully explained only by acoustic factors (Job, 1988). Fields (1993) evaluated various non-acoustic variables suggested in existing literature (136 survey studies) and concluded that noise annoyance is not affected by the noise level, amount of time spent at home, type of interviewing method, or demographic characteristics such as age, sex, social status, income, education, home ownership, type of dwelling, and length of residence. He reported that the following five variables have great impacts on annoyance: fear of danger from the noise source, noise prevention belief, general noise sensitivity, belief about the importance of the noise source, and annoyance with the non-noise impact of the noise source. Miedema and Vos (1999) reviewed several studies on annoyance and examined impacts of the following variables on annoyance: sex, age, education level, occupational status, size of household, homeownership, dependency on the noise source, and use of the noise source, noise sensitivity, and fear of the noise source. They found that fear of the noise source and noise sensitivity had great impacts on annoyance. Of the demographic variables, age had a small impact on annoyance.

Laboratory studies have been carried out in order to explore various non-acoustic factors affecting subjective responses to noise. Öhrström et al. (1980) earlier conducted a laboratory study to investigate annoyance rated to 13 different acoustic stimuli. The participants ($N = 40$) were presented with various sounds which covered not only neighbour noise but also transportation and machinery noises. Their stimuli included sounds of rifle shots, military aircraft, dripping water tap, pop music from neighbours, ambulance, motorcycle, lorry, passenger aircraft, train, dog, moped, tram, car, etc. The stimuli were played with peak noise levels of 70 and 80 dBA when the background noise level was 36 dBA. Annoyance increase as the noise level increased. In addition, of the transportation noise stimuli, the lorry noise was less annoying than other sources at the same noise level. The irregularity of the noise exposure was also reported to influence the response. Moreover, the authors highlighted that the annoyance reaction needed to be predicted not only by acoustic factors but non-acoustic factors such as individual experiences of the noise. Maris et al. (2007) conducted a laboratory experiment in which participants ($N = 117$) were exposed to eleven aircraft pass-bys at 50 and 70 dBA ($L_{\mathrm{eq,15\text{-}minute}}$) which were 68 and 88 dBA (L_{max}), respectively. The participants were given a reading task while the stimuli were being played. The participants were also given an option either that they can manage the noise (e.g. participants could voice their preference for a certain sound sample) or that they cannot do so. The results showed that annoyance associated with the noise level and the option of noise management led to the decrease in annoyance when the noise level was disturbing (70 dBA). Ryu and Jeon (2011) carried out both survey and laboratory studies with a total of 512 participants in order to examine the influence of noise sensitivity on the annoyance caused by indoor residential noises and outdoor traffic noise. Noise sensitivity was a significant determinant of annoyance caused by indoor and outdoor noises. They also found that annoyance evoked by indoor noise was affected more by noise sensitivity than that of outdoor noise.

Social surveys and interviews have been widely utilised to investigate non-acoustic factors in the research fields of environmental noise. In particular, non-acoustic factors of wind turbine noise have been commonly studied using the methods. Pedersen and Persson Waye (2004) conducted a social survey study to evaluate the prevalence of annoyance due to wind turbine noise. They collected the survey responses from residents in southern Sweden where more than 40 wind turbines were located ($N = 351$). It was found that the noise level increased annoyance. In comparison to transportation noises, wind turbine noise annoyance increased more quickly with the increasing noise level. The authors discussed that the visibility of wind turbines might influence annoyance responses. The respondents' attitude towards the visual impact of wind turbines on the landscape scenery affected the annoyance. Pedersen and Persson Waye (2007) later reported about another social survey study with residents in seven different areas in Sweden where wind turbines are located with a power of more than 500 kW ($N = 754$). They found that the noise level had positive correlations with noticeability and annoyance. Moreover, residents living in rural environments (e.g. low background noise level), particularly areas with hills and rocky features, were more annoyed by the wind turbine noise than those in the suburban area. Pedersen et al. (2009) presented consistent results in a later study conducted in the Netherlands. Responses were collected from residents living within 2.5 km of a wind turbine ($N = 725$). The results showed that the noise level increased annoyance and the effect was greater than transportation noise or industrial noise at comparable levels. The authors highlighted some factors that wind turbine noise exposure has: specific sound properties such as a "swishing" quality, temporal variability, lack of night-time abatement, visibility from the dwelling, and perceived attitude towards the visual impact of wind turbines on the landscape. Some non-acoustic factors such as visibility or attitude towards the visual impact of wind turbines on the landscape were discussed to interfere with the relationship between annoyance and noise level.

Studies on transportation noise have also used social surveys and interviews in order to explore non-acoustic factors. Leonard (1973) earlier found airport noise exposure evoked annoyance. He carried out 1,465 face-to-face interviews (1,103 of them participated in the telephone follow-up interviews). He measured annoyance with 11 question items including those asking disturbance with activities (e.g. "interferes with listening to radio or TV"), any impacts on moods (e.g. "makes you feel tense and edgy"), or any experienced influence on physical objects (e.g. "makes the TV picture flicker"). From the data collected by face-to-face interviews and telephone interviews with residents living close to one of the airports in the US, it was reported that the exposure to aircraft noise evoked residents to experience annoyance. He also asked the respondents about some intervening variables (e.g. fear of aircraft operation) in order to examine the variables' effects on the relationship between noise exposure and annoyance. He addressed that fear of aircraft operations and concern with the harmful effects of aircraft noise were the major intervening variables affecting the annoyance response. Increases in noise exposure and misfeasance beliefs were also likely to increase annoyance but he suggested that it would be highly likely only when the fear and health concerns were increased together, emphasising the significance of the two intervening variables on aircraft noise annoyance. Bluhm et al. (2004) conducted social surveys to study road traffic noise effects. Residents living close to main roads and highways ($N = 657$) responded to the questionnaire. The respondents were grouped into those living in areas where road traffic levels ($L_{\text{eq,24-hour}}$) were lower than 45 dBA, between 46 and 50 dBA, between 50 and 55 dBA, and higher than 55 dBA. It was found that annoyance increased as the road traffic noise level increased. The orientation of the bedroom window and satisfaction with residence had impacts on the prevalence of the road traffic noise annoyance. They also examined the impacts of gender, age, length of residence (i.e. the longer residency may cause habituation), and type of housing (e.g. single-family vs. multi-family housing), but there was no significant impact of those factors. Abo-Qudais and Abu-Qdais (2005) collected 492 survey responses to study road traffic noise annoyance. They revealed that the noise exposure associated with annoyance and disturbance in daily routine activities. In addition, income and education level associated with annoyance and awareness about the health impact of the noise. Annoyance had links with marital status and gender. Kroesen et al. (2008) conducted questionnaire surveys with residents living around an airport (*N* = 646) and tested the relationships between several variables explaining the experience of exposure to aircraft noise. They tested length of residency, age of the respondent, noise sensitivity, perceived disturbance, noise annoyance, perceived control or coping capacity, negative attitudes towards the noise source authorities and noise policy, belief of that noise can be prevented, positive social evaluation of the noise source, negative expectations related to noise development, personal dependency on noise source, concern about negative health effects of noise and pollution, annoyance by non-noise effects such as vibrations, dust, and odour, fear related to noise source, and concern about property devaluation. They found that most of the attitudinal variables directly or indirectly influenced one's perceived control and coping capacity which directly associated with noise annoyance. Dratva et al. (2010) studied the survey responses from 5,021 participants and reported female participants reported higher road traffic noise annoyance and annoyance associated with health-related quality of life. Schreckenberg et al. (2010) reported the data collected from 190 residents living within 40 km from Frankfurt Airport. They investigated annoyance caused by aircraft and road traffic noises. Not only the annoyance response, but they also examined perceived mental and physical health, perceived environmental quality, and noise sensitivity. Their results showed that noise sensitivity associated with total noise annoyance, aircraft noise annoyance, as well as physical health. Pierrette et al. (2012) investigated annoyance perceived by combined (road traffic and industrial) outdoor environmental noise by conducting face-to-face interviews with residents (*N* = 99). They generated noise maps based on the 24-hour noise measurements in the study areas. It was found that residents' annoyance rated to the combined noise increased as the noise level increased. They reported that age, gender, and length of residence did not associate with annoyance but fear of industrial sites and noise sensitivity had impacts on the annoyance. Okokon et al. (2015) carried out a survey study in order to evaluate the road traffic noise annoyance response. The respondents (*N* = 1,112) answered questions regarding health-risk perceptions, self-reported annoyance, and noise sensitivity. The results showed that annoyance associated with knowledge of health risks from the noise and noise sensitivity. Knowledge of health risks and positive environmental attitudes associated with higher noise sensitivity. Table 2-1 summarises some of the existing studies which have found acoustic or non-acoustic factors affecting subjective responses to the noise. The list is sorted in ascending order of the publication year.

Table 2-1. Studies on impacts of acoustic factors on noticeability and annoyance.

Study	Method	Noise source	Findings
Leonard (1973), USA	Interview *N* = 1,465	Aircraft noise	▪ Annoyance associated with noise exposure. ▪ Intervening variables (e.g. fear of aircraft operation and concern for harmful effects on health) affected the relationship between noise exposure and annoyance.
Fidell et al. (1979), USA	Laboratory *N* = 30	Various sound clips with different background sounds	▪ Positive correlations between noticeability and annoyance. ▪ Rising background noise decreased the correlation between noticeability and annoyance.
Öhrström et al. (1980), Sweden	Laboratory *N* = 40	Various noises	▪ Annoyance correlated with the noise level (L_{eq}). ▪ Type of noise source affected noise annoyance: Lorry noise was the least annoying. ▪ The irregularity of the noise affected the responses.
Öhrström et al. (1988), Sweden	Laboratory *N* = 93	Road traffic noise and impulse noises (a pure 1000 Hz tone, white noise, and a rattling noise)	▪ Annoyance highly correlated with self-report noise sensitivity and with the attitude to noise. ▪ Annoyance had a relationship with neuroticism.
Poulsen (1991), Denmark	Laboratory *N* = 72	Road traffic noise and synthetic gunfire noise	▪ Session length did not affect annoyance.
Belojević et al. (1992), Sweden	Laboratory *N* = 45	Road traffic noise	▪ Noise sensitivity increased noise annoyance.
Stansfeld et al. (1993), UK	Survey *N* = 2,398	Road traffic noise	▪ Noise-sensitive participants were more likely to be highly annoyed by noise

Study	Method	Noise source	Findings
			exposure than less noise-sensitive participants. ▪ There was no direct impact of noise exposure level but there were provocative interactions with noise sensitivity.
Schomer and Wagner (1996), USA	Field $N = 25$	Aircraft noise and railway noise	▪ Noticeability and sound exposure level had positive correlations. ▪ Type of noise source (e.g. helicopter or commercial jet aircraft) affected the response. ▪ Noticeability and annoyance had positive correlations.
Versfeld and Vos (1997), Netherlands	Laboratory $N = 20$	Road traffic noise	▪ Type of noise source (e.g. heavy vehicle) affected annoyance. ▪ Frequency of the spectrum was assumed to have impacts on the responses.
Kurra et al. (1999), Japan	Laboratory $N = 64$	Aircraft, railway, and road traffic noises	▪ Noise level had an impact on annoyance.
Staples et al. (1999), USA	Survey $N = 358$	Aircraft noise	▪ Assessment of environmental noise risk predicted disturbance from the noise. ▪ Disturbance did not associate with general annoyance or noise sensitivity.
Haines et al. (2003), UK	Interview N = 36; 18	Aircraft and road traffic noises	▪ Children’s everyday activities were affected by aircraft noise. ▪ Amount of control over the noise source influenced the range of coping strategies. ▪ Children’s emotional response to noise was consistent with adults’ reactions.
Sneddon et al. (2003), USA	Laboratory $N = 10$	Various sound clips with different background sounds	▪ Detectability and annoyance had positive correlations. ▪ Background sounds affected the responses.
Bluhm et al. (2004), Sweden	Survey $N = 657$	Road traffic noise	▪ More annoyance and sleep disturbance were reported when $L_{\text{eq,24-hour}}$ was higher than 50 dBA. ▪ Habituation was found in sleep problems but not in annoyance. ▪ Higher annoyance and sleep problems were found when bedroom windows were facing streets. ▪ Satisfaction with residence had an impact on the frequency of annoyance responses.

Study	Method	Noise source	Findings
			▪ Residents in apartments had more sleep problems compared to residents in detached or semi-detached houses.
Miedema and Vos (2004), Netherlands	Field *N* = 1,875	Noises of stationary sources (shunting yards, a seasonal industry, and other industries)	▪ With the same noise level (yearly *DENL*), the seasonal industry caused less annoyance than the other industries, while the other industries caused less annoyance than the shunting yards. ▪ Age and noise sensitivity had impacts on the response.
Abo-Qudais and Abu-Qdais (2005), Jordan	Survey *N* = 492	Road traffic noise	▪ Annoyance and disturbance in daily routine activities associated with the noise. ▪ Income and education level associated with annoyance and awareness about the health impact of the noise. ▪ Marital status and gender associated with annoyance.
Jeon et al. (2006a), Korea	Laboratory *N* = 98	Impact noises (the impact ball, the tapping machine, the bang machine, and an adult jumping)	▪ Annoyance increased as the noise level increased.
Maris et al. (2007), Netherlands	Laboratory *N* = 117	Aircraft noise	▪ Annoyance associated with the noise level.
Öhrström et al. (2007), Sweden	Survey *N* = 1,953	Railway and road traffic noises	▪ Higher total annoyance was found in areas exposed to both railway and road traffic noises than in areas with one dominant noise source when the noise level was the same.
Pedersen and Persson Waye (2007), Sweden	Survey *N* = 754	Wind turbine noise	▪ Annoyance associated with the noise level. ▪ Rural residents perceived higher annoyance than those in the suburban area.
Kroesen et al. (2008), Netherlands	Survey *N* = 646	Aircraft noise	▪ Annoyance had significant relationships with noise sensitivity, attitudinal factors, and perceived control.
Jakovljević et al. (2009), Serbia	Survey *N* = 3,097	Road traffic noise	▪ Noise annoyance showed strong correlations with noise levels, personal characteristics, and some housing conditions.

Study	Method	Noise source	Findings
Jeon et al. (2009a), Korea	Laboratory *N* = 20	Impact ball noise	▪ Annoyance increased as the noise level increased and as the interaural cross-correlation decreased.
Pedersen et al. (2009), Netherlands	Field *N* = 725	Wind turbine noise	▪ Annoyance increased as the noise level increased. ▪ Wind turbines' characteristics ("swishing" quality, temporal variability, and lack of night-time abatement) made the noise perceived to be more annoying than transportation noise and industrial noise. ▪ Visibility increased annoyance. ▪ Annoyance strongly correlated with a negative attitude towards the visual impact of wind turbines on the landscape.
Dratva et al. (2010), Switzerland	Survey *N* = 5,021	Road traffic noise	▪ Female participants reported higher noise annoyance. ▪ Annoyance associated with health-related quality of life.
Jeon et al. (2010a), Korea and UK	Laboratory *N* = 20	Road traffic and construction noises	▪ Higher annoyance was found when combined noises were presented than individual noises. ▪ Annoyance associated with the type of construction noise in combination with road traffic noise and the level of the road traffic noise.
Jeon et al. (2010b), Korea	Survey and laboratory *N* = 512	Neighbour noise (floor impact, airborne, drainage) and road traffic noise	▪ Dissatisfaction and annoyance correlated with the noises. ▪ Floor impact noise had stronger correlations with dissatisfaction and annoyance than other noise sources.
Schreckenberg et al. (2010), Germany	Interview *N* = 190	Aircraft and road traffic noises	▪ Noise sensitivity influenced total noise annoyance and aircraft noise annoyance.
Shepherd et al. (2010), New Zealand	Survey *N* = 105	Aircraft noise	▪ Noise sensitivity associated with health-related quality of life. ▪ Annoyance and sleep disturbance mediated the effects of noise sensitivity on health.
Ryu and Jeon (2011), Korea	Survey and laboratory *N* = 512	Neighbour noise (floor impact, airborne, and drainage) and	▪ Noise sensitivity correlated with annoyance. ▪ Stronger correlations between sensitivity and annoyance to indoor neighbour noise than outdoor traffic noise.

Study	Method	Noise source	Findings
		road traffic noise	
Pierrette et al. (2012), France	Interview *N* = 99	Road traffic and industrial combined	▪ Combined (road traffic and industrial) noise annoyance associated with noise levels. ▪ Fear of industrial sites and noise sensitivity associated with the annoyance. ▪ Age, sex, and length of residence did not associate with annoyance.
Lee and Jeon (2013), Korea	Laboratory *N* = 20	Road traffic, construction, and ventilation noises	▪ Loudness and roughness accounted for the annoyance of the combined noise.
Okokon et al. (2015), Finland	Survey *N* = 1,112	Road traffic noise	▪ Annoyance associated with knowledge of health risks from the noise and noise sensitivity. ▪ Knowledge of health risks and positive environmental attitudes associated with higher noise sensitivity.

2.3.2 Emotional expression

As Cohen and Weinstein (1981) noted, annoyance can be seen as a mild form of anger. Anger provokes when there is perceived harm which was judged as avoidable and undeserved. In other words, noise annoyance is a mild form of anger evoked by the noisy situation which may include threats to health or block behavioural goals (e.g. sleeping). Further, the responses could be evoked simply by being exposed to an aversive stimulus. Guski (1999) defined annoyance as a negative evaluation of environmental condition which associates with a number of negative psychological perceptions as follows: disturbance, aggravation, dissatisfaction, concern, bother, displeasure, harassment, irritation, nuisance, vexation, exasperation, discomfort, uneasiness, distress, and hate. Given that annoyance response is very closely linked to emotional responses, emotions cannot be overlooked when it comes to research on psychological effects of noise. Västfjäll (2002) carried out a laboratory study with university students (*N* = 44) to examine the relationship between the current mood and annoyance judgement. He measured the participants' self-reported noise sensitivity and annoyance, asked the participants to recall a memory from their own life when they experienced annoyance. He reported that the participants whose current mood involved annoyance rated noise annoyance higher than those who reported their mood as neutral.

Emotion has been defined as a response to a stimulus as well as a quality of excitement that accompanies instinctive reactions (Bentley, 1928). In order to understand the specific emotions provoked by stimuli, different types of stimuli have been used in laboratory experiments. Among them, the most commonly used stimuli are visual images, such as photographs and video clips. For example, Greenwald et al. (1989) measured emotions and physiological responses after the presentation of photographic images evoking different emotions (e.g. happy baby or angry face). Acoustic stimuli have also been used to investigate emotions, with variations in sound source and acoustic characteristics. In particular, a majority of acoustic stimuli include outdoor noises such as environmental noise. Namba et al. (1991) developed adjective lexicons in five different languages in order to describe subjective impressions to acoustic stimuli, including road traffic and construction noises. Using cluster analyses, they found that the road traffic and construction noises were grouped together and that the lexicon 'unpleasing' was closely tied to 'annoying' and 'noisy' in most languages. Grimwood (1993) carried out a group discussion with participants who were exposed to different noises consisting of environment and neighbour noises. It was reported that three levels of emotional reactions are caused by noises heard at home. The following figure (Figure 2-4) illustrates the three levels of noise exposure and the process of residents' reactions to the noise proposed by Grimwood (1993). Responses related to neighbour noise exposure has been particularly linked with emotional responses. Stansfeld et al. (2000) pointed out that noise from neighbours is a major source of annoyance and emotional responses in an urban environment but it was addressed that its impact has not been studied adequately. Stokoe and Hepburn (2005) analysed discourses of dispute mediation interviews, and the interview extracts clearly showed how residents react to and perceive their neighbours and their noise. Specifically, the interviewees who had disputes with their neighbours described their neighbours as unreasonable, irrational, unaccountable, and distressing. Particularly in the case of neighbour noise, residents may perceive intense negative emotion towards the noise source (i.e. neighbours) as shown in the third level of noise exposure in Figure 2-4. The emotions may result in retaliatory behaviours such as murders (Park, 2015a).

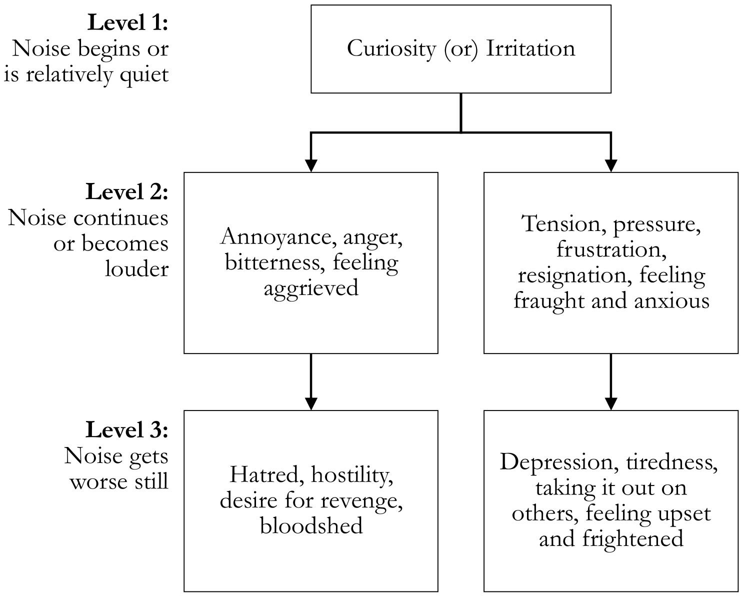


Figure 2-4. The process of noise reaction explained with three levels of noise exposure (Grimwood, 1993).

There are diverse ways to examine emotions since emotion is expressed in various forms (Morgan et al., 1979). One of the ways to assess emotions is to use language, verbal expressions, and lexicons. Russell (1980) plotted emotion lexicons on a circular model comprising two dimensions (i.e. pleasantness and arousal) and showed the inter-relationships between the emotions. Since Russell (1980) proposed the model, a few studies have also attempted to group emotions on the dimensional model based on their psychological conditions. Fehr and Russell (1984) conducted a series of study to group emotion lexicons under a certain number of prototypes and to validate the grouping procedure. Likewise, Ortony et al. (1987) collected a number of lexicons from the literature on emotions and categorised them into eight groups, including physical, affective, and cognitive states. These eight categories were then tested in Clore et al. (1987) by asking people to rate the emotion lexicons. The most discriminable categories were affective, cognitive, external, and bodily conditions. Instead of using the dimensional model, Shaver et al. (1987) examined the hierarchical structure of emotion concepts and specified prototypes of the emotion categories. They collected 213 emotion lexicons and categorised them into the six groups of love, joy, surprise, anger, sadness, and fear based on subjective ratings.

2.3.3 Physiological response

Emotion can also be measured using physiological reactions because physiological parameters are responsive to various emotional states including threat, frustration, anger, startle, and (un)pleasantness. In order to investigate affective responses through physiological measures, various stimuli including acoustic modalities have been used in experimental settings to (Bradley and Lang, 2007). The physiological measurements are useful for identifying emotions of which the perceiver is unaware (Öhman and Soares, 1994) and the emotion assessment using lexicons is beneficial to supplement the physiological measurement because physiological reactions can be partially influenced by psychological or physical activities (Cacioppo et al., 2000; Matsumoto et al., 2008).

Bradley and Lang (2000) conducted laboratory experiments to examine the relationship between emotion and physiological reactions. The participants (N = 183 in total) rated pleasantness and arousal elicited by each of 60 acoustic stimuli and their physiological responses were measured. It was reported that the acoustic stimuli rated as unpleasant resulted in greater startle reflexes, more corrugator supercilii muscle activities, and larger heart rate deceleration than the acoustic stimuli which were rated as pleasant. Electrodermal activities were larger for emotionally arousing than for neutral stimuli. Gomez and Danuser (2004) conducted a laboratory study in order to assess the relationships between emotion judgments and physiological responses to acoustic stimuli. They used

16 environmental noises and 16 musical fragments for 30 seconds to the participants (*N* = 31). The low-arousal evoking noise stimuli accelerated breathing when pleasantness was judged as low. Skin conductance level only increased with arousal ratings of music, while the mean heart rate only increased with arousal ratings of noise. Hume et al. (2008) carried out a laboratory study with 51 participants. The participants' physiological responses were measured while they were exposed to various sound clips including different sounds of natural, human, and transportation. The results showed heart rate decreased and respiratory rate increased when the stimuli were presented. They found some gender differences in the responses. Tajadura-Jiménez et al. (2010) investigated the moderating effect of perceived auditory space on the emotional response to sounds. The participants (*N* = 20) were exposed to acoustic spaces of different sizes and room acoustic properties along with diverse sound source positions. They used natural and artificial sounds as stimuli which were divided into negative and neutral emotional categories. They found small rooms were perceived as more pleasant, calmer, and safer than big rooms. The sounds heard behind the listeners tended to be more arousing, and elicited larger physiological changes than sources in front of the listeners. The response was more pronounced when the natural acoustic stimuli were played. Electrodermal activity closely correlated with the subjective responses. Hume and Ahtamad (2013) examined the association between the subjective evaluations of different sounds and physiological responses to the sounds. The participants (*N* = 80) were exposed to various sound clips including kids playing, clapping, evening birdsong, and some traffic sounds) for eight seconds. In general, it was found that heart rate decreased and respiration rate increased when the stimuli were presented. In particular, unpleasant acoustic stimuli caused larger falls in heart rate, while more pleasant sound stimuli resulted in bigger rises in respiratory rate. They also reported that the changes were greater in male participants' responses.

Not only do physiological measurements associate with emotional responses, but they also provide understanding into potential health effects of noise exposure.

There have been a number of laboratory studies which examined diverse physiological responses evoked by noises. Andrén et al. (1980) conducted a laboratory study with 18 participants in order to evaluate physiological responses to industrial noise. The noise stimuli were played at 95 dBA for 20 minutes and the responses were compared with the resting period at 40 dBA. The results showed that diastolic blood pressure increased as the noise level increased. Heart rate and systolic blood pressure did not significantly change as the noise level increased. In addition, all responses recovered to their initial levels 10 minutes after discontinuation of noise stimulation. Björk (1986) measured physiological reactions to various acoustic stimuli. In the first experiment, six stimuli were presented to the participants (*N* = 30). The stimuli included sounds of a man reading, a baby crying, people laughing, bubbling of the sea, cries of black-headed gulls, and song of birds. In the second experiment, the participants (*N* = 28) were exposed to eight stimuli including white noise, the scream of a rat, a call of a lapwing, bubbling of the sea, the vowel of a man, roar of a puma, a baby crying, and a tone of 2,000 Hz. It was observed that electrodermal activity increased when the noise level exceeded 70 dBA. Carter and Beh (1989) investigated cardiovascular functioning when intermittent noise was presented. The participants (*N* = 60) were exposed to noise burst (1/3 octave band noise centred at 4,000 Hz) at 92 dBA in three different conditions. In the first condition, the noise burst lasted for 4.5 seconds every 60 seconds. In the second condition, the noise burst lasted for 4.5 seconds with varying intervals from 20 to 100 seconds. In the third condition, the noise burst lasted differently ranging from 0.5 to 8.5 seconds with varying intervals from 20 to 100 seconds. The results showed that the intermittent noise exposure significantly increased diastolic and mean blood pressure. Heart rate increased but more significantly in those who received the unpredictable noise bursts. Holand et al. (1999) examined the effects of an auditory startle stimulus on physiological responses. The participants (*N* = 25) were presented with two startling stimuli at 110 dBA which lasted for 0.15 seconds with a 5-minute interval. They discovered that noise exposure increased blood pressure and heart rate. The responses followed immediately after the blink and were observed in the early exposure between 0 and 10 seconds. Griefahn et al. (2008) studied the effects of aircraft, railway, and road traffic noises on physiological responses. The data were collected from 24 participants and they found that heart rate increased as the noise level increased. They also reported the changes in heart rate as time went by. It was reported that heart rate reached to maximum after 4 to 11 seconds and dropped to the minimum below the baseline after 12 to 23 seconds. They also reported that heart rate again increased towards the baseline. Since the cardiac responses did not show any habituation to traffic noise during the night, they suggested that traffic noise would be likely to cause cardiovascular disease. Alvarsson et al. (2010) measured skin conductance levels of the participants ($N = 40$) when natural and road traffic noises were played. Skin conductance levels recovered faster when the natural sound was presented than during the exposure of road traffic noise.

Another way of examining physiological responses to noise has been to monitoring sleep disturbance caused by noise exposure. Vallet et al. (1983) studied the adverse health effects of road traffic noise. They performed a field study at participants' homes ($N = 26$). Long-term sleep disturbance was observed in the study. The participants under 45 years old showed stage 3 and 4 deficits whilst those over 45 years old showed REM sleep deficits. When it comes to the noise level, long-term average and peak levels were reported to be important in assessing sleep disturbance. Moreover, heart rate and heart rate variability increased during the noise but it was not significant. Eberhardt et al. (1987) carried out laboratory experiments with a total of 10 participants. The participants slept a total of six nights in the laboratory where road traffic noise was being played. They observed that the intermittent noise of 45 dBA caused transitions towards lighter sleep and that of 55 dBA had awakening effects. It was discussed that the responses were caused by arousal reactions of the noise peaks from the background rather than the absolute noise peak level. The continuous noise of 45 dBA caused the REM sleep deficits, while intermittent traffic noise of 45 dBA caused stage 3 and 4 deficits. In addition, low subjective sleep quality and adverse mood changes were reported after nights with REM sleep deficits. Öhrström (1995) carried out a laboratory study in which 12 participants slept eight nights in the laboratory. The participants were exposed to 16, 32, 64 and 128 noise events, respectively during four of the nights. The maximum noise level was 45 dBA. They reported that subjective sleep quality significantly decreased when 32 noise events were played per night. More than half of the participants reported they experienced difficulties in falling asleep when 64 noise events were presented. The noise exposure had significant impacts on body movements and the number of awakenings. There was a significant increase in tiredness during the day after nights with noise exposure no matter how many noise events were presented. Smith et al. (2013) carried out a laboratory study with 12 participants in order to evaluate the impact of railway noise on sleep disturbance. The participants slept in the laboratory for six nights. It was found that sleep quality and heart rate associated with low-frequency noise of trains. They discovered the changes in heart rate; it increased at the beginning followed by a deceleration to below the baseline.

Furthermore, the adverse health effects of noise have also been studied by directly measuring participants' subjective health complaints or their physiological parameters. Knipschild (1977) earlier carried out a social survey in order to investigate the health effects of aircraft noise. He collected 3,595 responses from residents in the less noisy area and 2,233 from those in the more noisy area. Heart trouble, hypertension, high blood pressure, and abnormal heart shape were observed more in the noisy area. It was reported that more cardiovascular drugs were taken by females. van Dijk et al. (1987) conducted a field study in order to investigate the health effects of industrial noise. Based on the 552 responses, they found that dizziness, hoarseness, and blood pressure did not associate with the noise exposure. Annoyance associated more with annoying noise sources, mental workload, and time pressure than noise level itself. Kristal-Boneh et al. (1995) also conducted field measurements with 3,106 blue-collar workers in order to investigate the effects of industrial noise exposure on people's physiological responses. They presented that noise intensity associated with resting heart rate and noise level increased heart rate. Regecová and Kellerová (1995) assessed the relationship between long-term exposure to road traffic noise and blood pressure in children. They measured blood pressure and heart rates of children aged from three to seven (*N* = 1,542) and measured the noise level near their kindergartens and homes for 24 hours. The results revealed that the noise levels above 60 dBA had significant impacts on children's blood pressure and heart rates. Evans et al. (1998) conducted field research in order to examine the association between aircraft noise exposure and children's physiological responses. The study was carried out with 217 children living nearby one of the airports in Munich, Germany. They discovered that chronic aircraft noise exposure increased children's resting blood pressure and overnight epinephrine and norepinephrine. It depressed quality-of-life indicators. Wallenius (2004) conducted questionnaire surveys with 147 residents who were living in either noisy (above 55 dBA) or less noisy (below 55 dBA) areas. They investigated the road traffic noise exposure and subjective health complaints. The results showed that general health and somatic symptoms (e.g. trouble in breathing, faintness, and dizziness) associated with noise exposure. Annoyance and disturbance of daily activities interacted with the general health and somatic symptoms. Aydin and Kaltenbach (2007) observed residents in the vicinity of an airport (*N* = 53). The residents were either from an area with the higher noise exposure or from an area with the lower noise exposure of aircraft. It was observed that those who were exposed to more aircraft noise of 50 dBA showed higher average blood pressure. Fyhri and Aasvang (2010) assessed the relationships between long-term noise exposure, annoyance, sleeping problems, and subjective health complaints. They conducted questionnaire surveys with a number of residents (*N* = 786) and compared the data with night-time noise levels calculated from outside of each respondent's dwelling, at the bedroom façade. They identified significant associations between night-time noise annoyance, sleeping problems, and some pseudoneurological complaints (palpitation, heat flushes, dizziness, anxiety, and depression). However, they reported that cardiovascular problems did not associate with noise exposure nor noise response. Bakker et al. (2012) conducted questionnaire surveys with residents of the Netherlands living in the vicinity of wind turbines (*N* = 725). The results presented close connections between wind turbine noise exposure, annoyance, self-reported sleep disturbance, and psychological distress. Babisch et al. (2013) evaluated the effects of road traffic and aircraft noises. From the collected data (*N* = 4,861) they found that aircraft noise associated with hypertension. The association was stronger in more annoyed participants. However, there was no association between hypertension and road traffic noise.

As various non-acoustic factors have been recognised to influence noise annoyance response (Job, 1988), research has examined the effects of non-acoustic factors on physiological responses. For instance, Stansfeld (1992) provided an extensive review of relationships between noise sensitivity and various responses to environmental noise. He addressed that greater awareness of external events contributed to the physiological responses or vice versa for the case of noise-sensitive individuals. In particular, it was addressed that high noise sensitivity associated with a higher level of physiological arousal, phobic, and defence/startle responses as well as slower habituation to noise.

In particular, Öhrström and Björkman (1988) carried out laboratory experiments in order to survey the effects of road traffic noise during the night-time. They monitored body movements, heart rate, subjective sleep quality, mood, and performance of participants with high or low noise sensitivity (*N* = 24). The participants slept 13 nights in the laboratory where road traffic noise was played. Its maximum noise level was 60 dBA and the noise exposure began at 22:30 and ended 07:30 in which 57 vehicles were presented. The participants responded to the questionnaires about sleep quality and mood every evening and morning. They revealed that noise events increased the number of body movements and heart rate. The noise-sensitive participants reported subjective low sleep quality and more movements. Both noise-sensitivity groups reported a slight decrease in mood and habituation was not found from the effects. The low noise-sensitivity group reported increased tiredness and the high noise-sensitivity group reported decreased extroversion after the noise exposure. Öhrström and Rylander (1990) then investigated the effect of the number of noise events on sleep. The participants had either high or low self-reported noise sensitivity (*N* = 28). They slept eight nights in the laboratory where road traffic noise was played. Its maximum noise level was either 50 or 60 dBA. The noise exposure began at 22:30 and ended at 07:30. The noise exposure consisted of 4, 8, 16 and 64 pass-bys of heavy vehicles. The results showed that sleep quality was affected the most by the number of noise events followed by noise sensitivity and noise level. The high noise-sensitivity group significantly affected by the number of noise events, while the low noise-sensitivity group was affected by the number of noise events only when the noise level was 60 dBA. Nivison and Endresen (1993) conducted a survey study in order to examine the effects of long-term exposure to road traffic noise on self-reports of health and sleep. The survey respondents (*N* = 82) responded to some questions such as health complaints, usual sleep patterns, psychosocial relations, anxiety, stressful life events, and attitudinal factors that could explain their responses to noise. The results revealed that there was no association between the noise level, health, and sleep. However, strong correlations were found between annoyance, sensitivity, and health complaints. Besides, female respondents presented stronger associations between poor sleep quality, health complaints, and noise sensitivity. The stronger correlations of the female respondents were explained by the degree of exposure to noise caused by their longer residence and greater time spent at home. Belojević et al. (1997) investigated the effects of road traffic noise exposure on residents' health. They interviewed 253 residents living in noisy areas where the ambient noise level was higher than 65 dBA and 160 residents living in less noisy areas with lower than 55 dBA of the ambient noise level. They discovered that residents in the noisy area reported more frequent sleep problems including difficulty in falling asleep, awakenings, tiredness after awakening, and poor subjective sleep quality. Those in the noisy area reported more frequent health complaints including headache, nervousness, fatigue, and feeling of depression. They also reported more frequent intention to change the place of living, duration of leaving windows open, and poor interpersonal relationship between neighbours.

From the results, the authors discussed that neuroticism, noise sensitivity, sleep disorders, and psychological disturbances correlated with each other. Björk et al. (2006) investigated the relationship between road traffic noise and annoyance, disturbance of daily activities, and general health. They carried out a social survey and collected responses from 13,557 respondents. It was shown that the noise exposure increased annoyance and disturbance of daily activities. Particularly, the association between noise exposure and hypertension was observed from the female respondents. They also reported unemployed respondents presented the association between stress and the noise exposure. Further, those with financial problems showed the association between concentration problems and noise exposure. Heinonen-Guzejev et al. (2007) studied the association of coronary heart and cardiovascular mortality with noise sensitivity. From the collected data (*N* = 1,495), they reported there was a significant increase in cardiovascular mortality from noise-sensitive female participants. Fyhri and Klæboe (2009) collected data from 1,842 residents (including face-to-face interviews in 8 sub-areas and telephone interviews in 14 areas) living in Oslo, Norway. They examined the effect of road traffic noise on hypertension and ischemic heart disease. It was reported that subjective health complaints (e.g. sleeping problems and nervousness) correlated with noise sensitivity and annoyance. Age was also reported to associate with all the health complaints except tiredness. Table 2-2 summarises some of the existing studies which have found physiological effects of noise or acoustic stimuli. The list is sorted in ascending order of the publication year.

Table 2-2. Studies on physiological responses to noise or acoustic stimuli.

Study	Method	Noise source	Noise effects
Knipschild (1977), Netherlands	Survey *N* = 3,595; 2,233	Aircraft noise	Heart trouble, hypertension, high blood pressure, and abnormal heart shape *Gender difference had an impact on the responses
Andrén et al. (1980), Sweden	Laboratory *N* = 18	Industrial noise	Diastolic blood pressure
Vallet et al. (1983), France	Field *N* = 26	Road traffic noise	Sleep disturbance

Study	Method	Noise source	Noise effects
			*Age difference had an impact on the responses
Björk (1986), Finland	Laboratory *N* = 30; 28	Various sound clips	Electrodermal activity
Eberhardt et al. (1987), Sweden	Laboratory *N* = 1; 9	Road traffic noise	Sleep disturbance and mood changes after sleep
Öhrström and Björkman (1988), Sweden	Laboratory *N* = 24	Road traffic noise	Sleep disturbance *Noise sensitivity had an impact on the responses
Carter and Beh (1989), Australia	Laboratory *N* = 60	Intermittent noise burst	Diastolic blood pressure, mean blood pressure, and heart rate
Öhrström and Rylander (1990), Sweden	Laboratory *N* = 28	Road traffic noise	Sleep disturbance *Noise sensitivity had an impact on the responses
Kristal-Boneh et al. (1995), Israel	Field *N* = 3,106	Industrial noise	Heart rate
Öhrström (1995), Sweden	Laboratory *N* = 12	Road traffic noise	Sleep disturbance and tiredness after sleep
Belojević et al. (1997), Yugoslavia	Survey *N* = 253; 160	Road traffic noise	Sleep disturbance, tiredness after sleep, headache, nervousness, fatigue, and feeling of depression *Neuroticism and noise sensitivity had impacts on the responses
Evans et al. (1998), Germany	Field *N* = 217	Aircraft noise	Blood pressure, overnight epinephrine and norepinephrine, and quality-of-life indicators
Holand et al. (1999), France	Laboratory *N* = 25	Acute loud noise	Blood pressure and heart rate
Bluhm et al. (2004), Sweden	Survey *N* = 657	Road traffic noise	Sleep disturbance *Window orientation and type of housing had impacts on the responses
Wallenius (2004), Finland	Survey *N* = 147	Road traffic noise	General health and somatic symptoms
Björk et al. (2006), Sweden	Survey *N* = 13,557	Road traffic noise	Sleep disturbance and hypertension *Gender difference, and employment, financial status had impacts on the responses
Griefahn et al. (2008), Germany	Laboratory *N* = 24	Aircraft, railway, and road traffic noises	Heart rate

Study	Method	Noise source	Noise effects
Hume et al. (2008), UK	Laboratory *N* = 51	Various sound clips	Heart rate and respiratory rate *Gender difference had an impact on the responses
Fyhri and Klæboe (2009), Norway	Interview *N* = 1,842	Road traffic noise	Sleeping problems and nervousness *Noise sensitivity and age difference had impacts on the responses
Alvarsson et al. (2010), Sweden	Laboratory *N* = 40	Road traffic noise and nature sounds	Skin conductance level
Hume and Ahtamad (2013), UK	Laboratory *N* = 80	Various sound clips	Heart rate, respiration rate, and electromyography *Gender difference had an impact on the responses
Lindborg (2013), Singapore	Laboratory *N* = 17	Various sound clips	Heart rate

2.4 Summary

This chapter presented the literature review which gives broad ideas of the current state of the research fields. The chapter began with a brief introduction on how stress responses have been conceptualised traditionally. Regarding noise as one of the environmental stressors, the chapter continued reviewing the existing studies which have focused on responses to various types of noise or acoustic stimuli. The studies reviewed in the chapter were on noticeability, annoyance, emotion, and physiological responses. Some studies focused on some residential indoor noise sources, but most of the studies concentrated on other environmental noise sources such as transportation noises. By identifying the lack of research on neighbour noise and floor impact noise, this chapter confirmed the very rationale for this whole research. In addition, it has given the author insights on how to set research objectives for each study and how to practically plan, design, and conduct the following studies in order to investigate psychological and physiological responses to floor impact noise.

3 Characteristics of noise events caused by upstairs neighbours in multi-family housing: Field measurements[*]

3.1 Introduction

Indoor noise level is a significant factor for occupants' health and well-being in residential buildings. Hence, the WHO suggests the guidelines for residential buildings based on 24-hour noise levels. A number of studies have reported environment noise levels in terms of L_{dn} or L_{den} (e.g. Fields, 1984; Paunović et al., 2009; World Health Organization, 2018). However, there is little research that examined neighbour noise for 24 hours. Consequently, 24-hour noise measurement is necessary for understanding acoustic comfort in homes. This study investigated different characteristics of noise events heard inside real houses of multi-family housing buildings. Field measurements were performed in 32 residences in multi-family housing in South Korea. Noise recordings were carried out at each residence in unoccupied conditions. The 24-hour recordings were compared between three different times: day (07:00 ~ 19:00), evening (19:00 ~ 23:00), and night

---

[*] This chapter has been partly published in a peer-reviewed journal and a conference proceeding. The papers can be found in Appendix 7.

(23:00 ~ 07:00). First, noise events which exceeded the threshold levels were collected. Then each noise source was identified. The noise level, length, and the number of occurrence of each source were analysed. The study was conducted based on the following research question and objectives as shown in Table 3-1.

Table 3-1. The research question and objectives of the present field study.

Research question	Objectives
▪ What kinds of indoor noise would be heard in real residences in heavyweight multi-family housing buildings?	▪ To investigate various noise events in real houses for long-term. ▪ To identify each noise event's characteristics: noise source, noise level, noise length, and the number of occurrence ▪ To examine the impact of slab thickness on floor impact noise exposure.

3.2 Methods

3.2.1 Sites

Thirty-two residences in multi-family housing buildings were recruited for the measurements. As listed in Table 3-2, 19 sites were in Seoul and the others were located in other cities of South Korea. All the sites were located in urban areas and all buildings were constructed as heavyweight buildings with the reinforced concrete structure. Net floor area of the sites ranged from 42 to 212.5 m^2. The oldest site was built in 1984 and the latest one was built in 2013. The number of bedrooms in each home varied from one to five. The number of bathrooms ranged from one to three. Slab thickness of each site ranged from 135 to 210 mm. Since Korean domestic regulation was strengthened in 2005, many of sites built earlier had slab thickness of 135 and 150 mm. Most sites were built with slabs thicker than 150 mm since then. The buildings were all different in heights. The shortest building had five floors (Site #2), whereas the tallest had 42 floors (Site #20). Two sites were on the first floors (i.e. ground floors in the UK) so they were the lowest (Sites #2 and #7) and the site located on the 32nd floor was the highest (Site #28). Distance from major roads also varied ranging from 21 to 181 m.

Table 3-2. Information of the residences which took part in the study. The sites are listed in the table in ascending order of the construction year.

No.	City	Recording location[a]	Month[b]	Net floor area [m²]	Year of construction	Number of bedroom	Number of bathroom	Slab thickness [mm]	Floor[c]	Distance from major roads [m]
1	Seoul	L	Feb	198.1	1984	5	2	135	12 (15)	181
2	Pyeongtaek	L	Jul	62.6	1989	2	1	135	1 (5)	80
3	Ulsan	L	Mar	97.0	1990	3	1	135	8 (15)	35
4	Daejeon	L	Aug	193.7	1992	5	2	150	2 (15)	26
5	Bucheon	L	Jun	42.0	1993	2	1	150	9 (17)	79
6	Goyang	B	Jul	158.6	1995	4	2	150	9 (15)	75
7	Seoul	B	Jul	105.7	1998	3	2	150	1 (15)	21
8	Seoul	L	Mar	107.3	1998	3	2	150	10 (19)	31
9	Seoul	B	Jun	87.5	1999	3	1	150	18 (22)	70
10	Seoul	L	Aug	84.5	1999	3	1	150	4 (15)	29
11	Seoul	L	Aug	109.6	1999	3	2	150	13 (22)	37
12	Seoul	L	Jul	108.5	2000	3	2	150	13 (24)	92
13	Seoul	L	Jul	88.0	2003	3	1	150	18 (22)	56
14	Seoul	L	Jul	96.7	2003	3	2	150	4 (7)	46
15	Seoul	L	Jul	110.0	2004	3	2	150	9 (15)	33
16	Seoul	L	Jul	151.0	2004	4	2	150	3 (13)	25
17	Seoul	L	Jul	106.9	2004	3	2	150	7 (16)	106

[a] L: living room; B: bedroom

[b] Month of the recording took place

[c] Floor of the apartment (the top floor of the building)

No.	City	Recording location[a]	Month[b]	Net floor area [m^2]	Year of construction	Number of bedroom	Number of bathroom	Slab thickness [mm]	Floor[c]	Distance from major roads [m]
18	Daegu	L	Feb	114.3	2005	3	2	150	12 (28)	87
19	Pocheon	L	Jul	99.8	2005	3	2	180	7 (18)	51
20	Seoul	L	Jul	107.6	2005	2	2	180	11 (42)	41
21	Seoul	L	Jul	84.9	2005	3	2	180	16 (19)	42
22	Seoul	L	Sep	106.2	2006	3	2	150	10 (29)	70
23	Yongin	L	Jul	107.7	2006	3	2	180	4 (23)	51
24	Namyangju	B	Jul	51.2	2008	2	1	180	2 (10)	87
25	Seoul	B	Jul	109.5	2008	3	2	180	19 (22)	36
26	Seoul	L	Sep	126.6	2008	4	2	180	20 (21)	171
27	Goyang	L	Apr	149.1	2009	4	2	180	3 (12)	22
28	Gunpo	L	Apr	212.5	2010	4	3	180	32 (34)	75
29	Seoul	B	Oct	56.2	2010	1	1	180	4 (13)	56
30	Paju	L	Jul	101.5	2011	3	2	210	7 (11)	123
31	Yongin	L	Jul	131.5	2012	3	2	210	14 (17)	61
32	Seoul	L	Sep	110.1	2013	3	2	210	2 (13)	110
M				111.8	-	3.1	1.8	-	-	65.8
SD				39.2	-	0.8	0.5	-	-	39.8
Min				42.0	1984	1	1	135	-	21
Max				212.5	2013	5	3	210	-	181

[a] L: living room; B: bedroom

[b] Month of the recording took place

[c] Floor of the apartment (the top floor of the building)

3.2.2 Procedure

The noise measurements were carried out in either living rooms or bedrooms under unoccupied conditions. The recording location of each site was chosen depending on the report of the residents living in each site that they could hear the most noise from upstairs. The measurements were conducted from the morning to the following morning for 24 hours while the residents vacated the site. All windows were double glazed and they were closed during the measurements to minimise the effects of outdoor noise. Heating, ventilation, and air conditioning (HVAC) were turned off. The refrigerators could not be turned off because all the sites were actual houses in which the occupants lived. Before starting the noise measurement, the entire measurement system was calibrated using an acoustic calibrator (Brüel & Kjær Type 4280). The noise was recorded using a half-inch free field microphone (Brüel & Kjær Type 4189) which was mounted on the tripods and positioned 1.2 m above the floor. The microphone was directly connected to the noise monitoring system (01dB DUO) which has the calibrated recording feature as an all-in-one device.

3.2.3 Data analysis

All data were exported from the noise monitoring system (01dB DUO) as one-minute interval noise levels. The data were then processed using data processing software (01dB dBTrait). All noise measurements were exported as $L_{\mathrm{Aeq,1\text{-}minute}}$ and L_{AFmax} according to the WHO guidelines (Berglund et al., 1999). Since the noise levels were exported by one-minute intervals, a total of 1,440 noise levels were derived for 24 hours per site. The 24-hour period was classified into the day (07:00 ~ 19:00), evening (19:00 ~ 23:00), and night (23:00 ~ 07:00) according to ISO 1996-2.

In order to identify noise sources, noise events exceeding threshold noise levels were identified. Based on the WHO recommendations, the threshold noise levels were set as 35 dBA (L_{Aeq}) for daytime, and 30 dBA (L_{Aeq}) and 45 dBA (L_{AFmax})

for night-time (Berglund et al., 1999). For daytime L_{AFmax}, there was no WHO recommendation so a threshold level of 50 dBA (L_{AFmax}) was adopted from the domestic guidelines of the Korean Government (Ministry of Land, Infrastructure and Transport, 2018). Noise source and length of the noise events were then identified by listening to the recordings. Time histories (exported with an interval of 125 ms) were of help to visually recognise the noise events at this stage. The time histories of each site can be found in Appendix 1. All noise events were classified into either airborne or structure-borne noise sources. Of the structure-borne noise sources, heavyweight and lightweight impact sources were also classified. The sources were identified based on objective characteristics. For example, adults' walking and children's running were identified mainly based on intervals between the steps (speed of footsteps). The L_{AE}, the equivalent sound level normalised to a period of one second, was used to analyse the noise levels of each noise source since the length of each noise event was different.

3.3 Results

3.3.1 The overall noise levels

Figure 3-1 displays box-plots of the overall L_{Aeq} for 24-hour, day, evening, and night. Box-plots are used in the figures in this section in order to present the median values. Among the three time periods (day, evening, and night), L_{Aeq} in the evening showed the widest variation. Median L_{Aeq} was the lowest at night. Table 3-3 shows the overall L_{Aeq} measured from each site. It was found that six sites (#2, #5, #8, #14, #18, and #32) exceeded the threshold levels in the daytime or evening (35 dBA, L_{Aeq}) and eight sites (#2, #5, #13, #14, #22, #23, #26, and #31) exceeded that of the night-time (30 dBA, L_{Aeq}). Three sites (#2, #5, and #14) exceeded all the threshold levels for day, evening, and night.

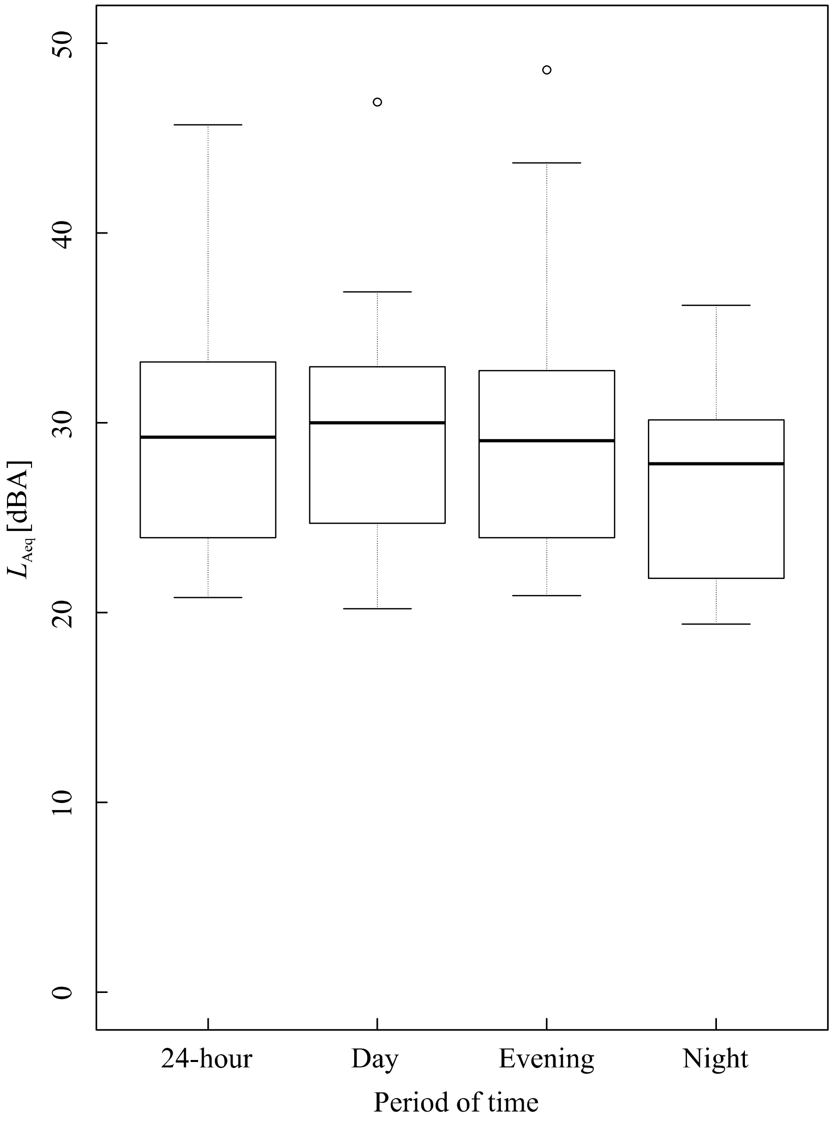


Figure 3-1. The overall L_{Aeq} for 24-hour, day, evening, and night.*

---

* The boxplots show median, first and third quartiles, minimum and maximum, and outliers. Each box represents the range of scores from first quartile to third quartile (i.e. inter-quartile range). Median is marked by the line that divides the box into two parts. The whiskers show minimum and maximum, and the small circles mark outliers.

Table 3-3. The overall L_{Aeq} of each site for 24-hour, day, evening, and night.

	L_{Aeq} [dBA]			
Site No.	Overall (24-hour)	Day (07:00 ~ 19:00)	Evening (19:00 ~ 23:00)	Night (23:00 ~ 07:00)
1	30.1	30.4	30.2	29.6
2	36.0	36.5^{+}	35.6^{+}	35.4^{+}
3	23.7	24.7	24.3	20.9
4	30.4	31.0	29.6	29.6
5	45.7	46.9^{+}	48.6^{+}	34.1^{+}
6	22.9	23.2	23.6	21.8
7	23.3	24.3	22.6	21.6
8	36.7	30.2	43.7^{+}	29.2
9	20.9	20.8	22.7	19.9
10	26.6	27.6	28.5	21.7
11	28.4	28.7	28.1	28.0
12	28.5	29.8	28.2	25.6
13	32.4	32.7	32.3	32.1^{+}
14	36.4	36.5^{+}	36.2^{+}	36.2^{+}
15	27.8	28.3	28.1	26.7
16	30.0	30.7	29.9	28.9
17	20.8	20.2	21.9	20.9
18	34.4	36.9^{+}	30.1	26.4
19	31.3	32.3	31.1	29.2
20	27.9	28.5	27.7	26.8
21	24.2	26.3	20.9	19.4
22	31.5	31.8	31.9	30.7^{+}
23	33.5	33.9	33.9	32.7^{+}
24	22.5	23.9	21.9	19.6
25	24.6	24.7	24.5	24.4
26	34.5	34.4	34.6	34.6^{+}
27	23.6	23.9	23.6	23.1
28	28.2	28.4	28.5	27.7
29	22.0	22.3	21.7	21.8
30	30.2	30.5	30.1	29.6
31	32.9	33.2	33.2	32.3^{+}
32	34.0	34.0	37.7^{+}	29.4
M	29.2	29.6	29.6	27.2
SD	5.7	5.6	6.4	5.0
Mdn	29.3	30.0	29.1	27.8
Min	20.8	20.2	20.9	19.4
Max	45.7	46.9	48.6	36.2

$^{+}$ above the threshold levels (35 dBA for day and evening; 30 dBA for night)

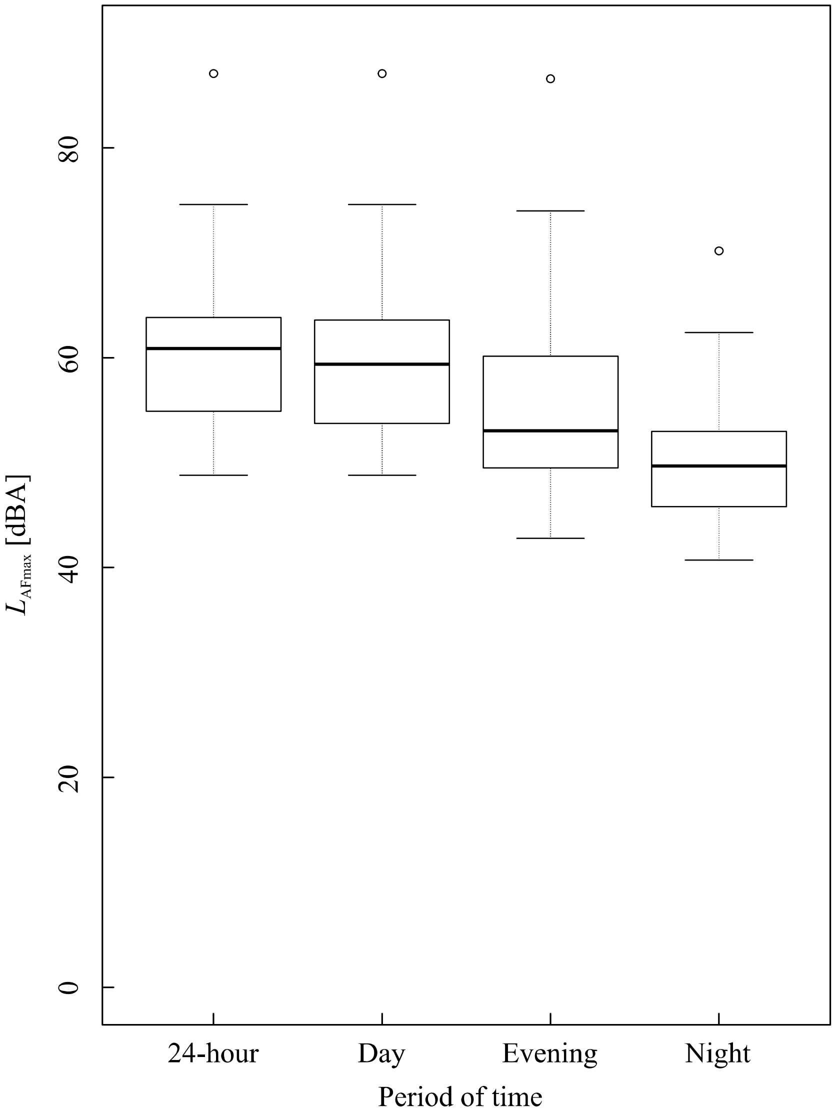


Figure 3-2. The overall L_{AFmax} for 24-hour, day, evening, and night.

Table 3-4. The overall L_{AFmax} of each site for 24-hour, day, evening, and night.

	L_{AFmax} [dBA]			
Site No.	Overall (24-hour)	Day (07:00 ~ 19:00)	Evening (19:00 ~ 23:00)	Night (23:00 ~ 07:00)
1	52.4	52.4$^+$	49.7	49.7$^+$
2	70.2	68.0$^+$	61.3$^+$	70.2$^+$
3	53.7	52.7$^+$	53.7$^+$	45.0
4	63.7	63.7$^+$	59.0$^+$	48.9$^+$
5	87.1	87.1$^+$	86.6$^+$	62.4$^+$
6	54.9	54.9$^+$	50.6$^+$	40.7
7	55.0	55.0$^+$	49.6	45.3$^+$
8	74.0	56.6$^+$	74.0$^+$	45.8$^+$
9	54.9	49.0	49.2	54.9$^+$
10	63.2	58.8$^+$	63.2$^+$	51.1$^+$
11	57.0	57.0$^+$	54.6$^+$	46.1$^+$
12	57.9	57.9$^+$	49.0	56.6$^+$
13	57.5	57.5$^+$	50.3$^+$	50.0$^+$
14	65.6	65.6$^+$	61.8$^+$	62.1$^+$
15	55.4	54.2$^+$	55.4$^+$	51.2$^+$
16	63.5	63.5$^+$	58.1$^+$	52.2$^+$
17	54.0	49.2	54.0$^+$	46.1$^+$
18	74.6	74.6$^+$	62.3$^+$	53.4$^+$
19	73.4	73.4$^+$	69.2$^+$	49.7$^+$
20	53.3	53.3$^+$	47.1	47.5$^+$
21	61.2	61.2$^+$	49.4	44.5
22	50.0	50.0	45.9	43.7
23	62.7	62.7$^+$	57.9$^+$	52.6$^+$
24	61.0	61.0$^+$	50.7$^+$	51.5$^+$
25	61.7	61.7$^+$	42.8	45.4$^+$
26	62.0	62.0$^+$	49.7	50.4$^+$
27	48.8	48.8	47.4	43.0
28	54.3	53.2$^+$	54.3$^+$	49.7$^+$
29	64.0	64.0$^+$	49.2	59.5$^+$
30	60.0	60.0$^+$	51.8$^+$	45.8$^+$
31	60.8	60.8$^+$	52.4$^+$	53.5$^+$
32	70.4	70.4$^+$	70.3$^+$	48.5$^+$
M	61.2	60.0	55.6	50.5
SD	8.3	8.4	9.3	6.3
Mdn	60.9	59.4	53.1	49.7
Min	48.8	48.8	42.8	40.7
Max	87.1	87.1	86.6	70.2

$^+$ above the threshold levels (50 dBA for day and evening; 45 dBA for night)

Figure 3-2 illustrates box-plots of the overall L_{AFmax} of 24-hour, day, evening, and night. Among the three time periods (day, evening, and night), L_{AFmax} of the evening presented the widest variation. Median L_{AFmax} was the lowest at night. Table 3-4 lists the overall L_{AFmax} of each site. Most of the sites exceeded the threshold levels in the daytime or evening (50 dBA, L_{AFmax}). Only Sites #9, #22, and #27 did not exceed the threshold levels in the daytime and evening. For the night-time noise, only five sites (#3, #6, #21, #22, and #27) did not exceed the threshold levels (45 dBA, L_{AFmax}). Sites #22 and #27 were the only sites which showed lower levels than the threshold levels for day, evening, and night.

There were a total of 1,440 noise levels exported for 24 hours per site because the data were derived with one-minute intervals. Table 3-5 lists the percentages of the whole noise levels of all the sites, in each of the noise level ranges. The table shows the ranges of noise levels below or equal to 30 dBA, between 30 and 40 dBA, between 40 and 50 dBA, and above 50 dBA. The L_{Aeq} from most of the sites (62.9 %) were below or equal to 30 dBA for 24 hours. Those between 30 and 40 dBA (L_{Aeq}) for 24 hours were 33.8 %. Those between 40 and 50 dBA (L_{Aeq}) for 24 hours were very low (0.2 %) and those higher than 50 dBA (L_{Aeq}) for 24 hours were 3.1 %. L_{Aeq} which exceeded the threshold levels were 12.2 % and 12.0 % for day and evening, respectively. In addition, 32.7 % exceeded the threshold level of the night-time L_{Aeq}. For the case of L_{AFmax}, 29.4 % were below 30 dBA for 24 hours. The table presents that 56.4 % were between 30 and 40 dBA (L_{AFmax}) and 12.9 % were between 40 and 50 dBA (L_{AFmax}) for 24 hours. Besides, 1.4 % were above 50 dBA (L_{AFmax}). L_{AFmax} which exceeded the threshold levels were 1.8 % for day, evening, and night.

Table 3-5. Percentages of (a) L_{Aeq} and (b) L_{AFmax} in each of the noise level ranges for 24-hour, day, evening, and night.

		Overall (24-hour)	Day (07:00 ~ 19:00)	Evening (19:00 ~ 23:00)	Night (23:00 ~ 07:00)
(a) L_{Aeq}	% ≤ 30 dBA	62.9	59.9	61.8	67.8
	30 < % ≤ 40 dBA	33.8	36.7	34.9	29.0
	40 < % ≤ 50 dBA	0.2	0.2	0.1	0.1
	% > 50 dBA	3.1	3.1	3.2	3.1
	% > threshold[a]		12.2	12.0	32.7
	Mdn [dBA]	29.3	30.0	29.1	27.8
	Min [dBA]	20.8	20.2	20.9	19.4
	Max [dBA]	45.7	46.9	48.6	36.2
(b) L_{AFmax}	% ≤ 30 dBA	29.4	22.1	23.2	43.4
	30 < % ≤ 40 dBA	56.4	60.0	58.1	50.2
	40 < % ≤ 50 dBA	12.9	16.1	16.9	6.0
	% > 50 dBA	1.4	1.8	1.8	0.4
	% > threshold[b]		1.8	1.8	1.8
	Mdn [dBA]	60.9	59.4	53.1	49.7
	Min [dBA]	48.8	48.8	42.8	40.7
	Max [dBA]	87.1	87.1	86.6	70.2

[a] 35 dBA for day and evening; 30 dBA for night

[b] 50 dBA for day and evening; 45 dBA for night

3.3.2 The number of occurrence of each noise source

Noise sources and their number of occurrence are listed in Table 3-6. Five sources were identified as airborne noise sources; it included public address (PA) system, domestic equipment such as vacuum machines, voice of adults, voice of children, and other sources such as musical instruments. The PA system represents the sounds announced by management offices. In South Korean apartment complexes, the management offices frequently announce important events or notices to all residents via a speaker installed on the wall or ceiling of the living room of each house. It was found that a total of 76 noise events were produced by airborne noise sources and the number of occurrence of children’s voice was the largest. The structure-borne noise was made by nine sources. It included the noises of adult's walking, children's running, children's jumping, movement of furniture, dropping of small objects, scraping of small objects, door banging, plumbing system, and hammering. The number of structure-borne noise events was 542. The number showed that structure-borne noise was dominant in the participated sites. The number of occurrence of furniture movement was the largest, followed by dropping of small objects, children’s running, and adults’ walking. In particular, the heavyweight and lightweight impact noises presented in Table 3-6 were generated by residents living upstairs of the sites except for the door banging noise. Of 54 door banging noise events, 17 were that of main entrance doors of neighbouring sites on the same floor which were accompanied by echoes in the hallway. Figure 3-3 shows the number of occurrence of each noise source for day, evening, and night. The majority of noise events occurred during the daytime. This was mainly because the period of daytime is the longest and the activities of the neighbours are most active at this period of time. For instance, movement of furniture, dropping of small objects, children’s running, and adults’ walking were dominant in the daytime. The number of occurrence of furniture movement was the largest during the day and this noise source was also observed during the evening and night. In particular, movement of furniture consisted of movements of various types of furniture (e.g. scraping noise of table or chairs, impact noise of chairs, etc.). Most of the events occurred at night were short impact noise of chairs. The noise of furniture movement lasted two times longer during the daytime than night.

Table 3-6. The number of occurrence of each noise source for 24-hour, day, evening, and night.

Noise source			Overall (24-hour)		Day (07:00 ~ 19:00)		Evening (19:00 ~ 23:00)		Night (23:00 ~ 07:00)	
			Number	%	Number	%	Number	%	Number	%
Airborne	PA system		13	2.1	8	61.5	5	38.5	0	0.0
	Domestic equipment (e.g. vacuum machine)		2	0.3	1	50.0	0	0.0	1	50.0
	Voice	Adults	12	1.9	3	25.0	8	66.7	1	8.3
		Children	34	5.5	28	82.4	6	17.6	0	0.0
	Others (e.g. musical instrument)		15	2.4	15	100.0	0	0.0	0	0.0
	Sum (airborne)		76	12.3	55	72.4	19	25.0	2	2.6
Structure-borne	Heavyweight impact	Adult's walking	68	11.0	53	77.9	9	13.2	6	8.8
		Children's running	89	14.4	68	76.4	17	19.1	4	4.5
		Children's jumping	24	3.9	17	70.8	7	29.2	0	0.0
	Lightweight impact	Movement of furniture	167	27.0	92	55.1	41	24.6	34	20.4
		Small object dropping	100	16.2	62	62.0	26	26.0	12	12.0
		Small object scraping	19	3.1	11	57.9	6	31.6	2	10.5
		Door banging	54	8.7	28	51.9	13	24.1	13	24.1
		Plumbing system	13	2.1	5	38.5	3	23.1	5	38.5
		Hammering	8	1.3	8	100.0	0	0.0	0	0.0
	Sum (structure-borne)		542	87.7	344	63.5	122	22.5	76	14.0
	Total number of occurrence		618	100.0	399	64.6	141	22.8	78	12.6

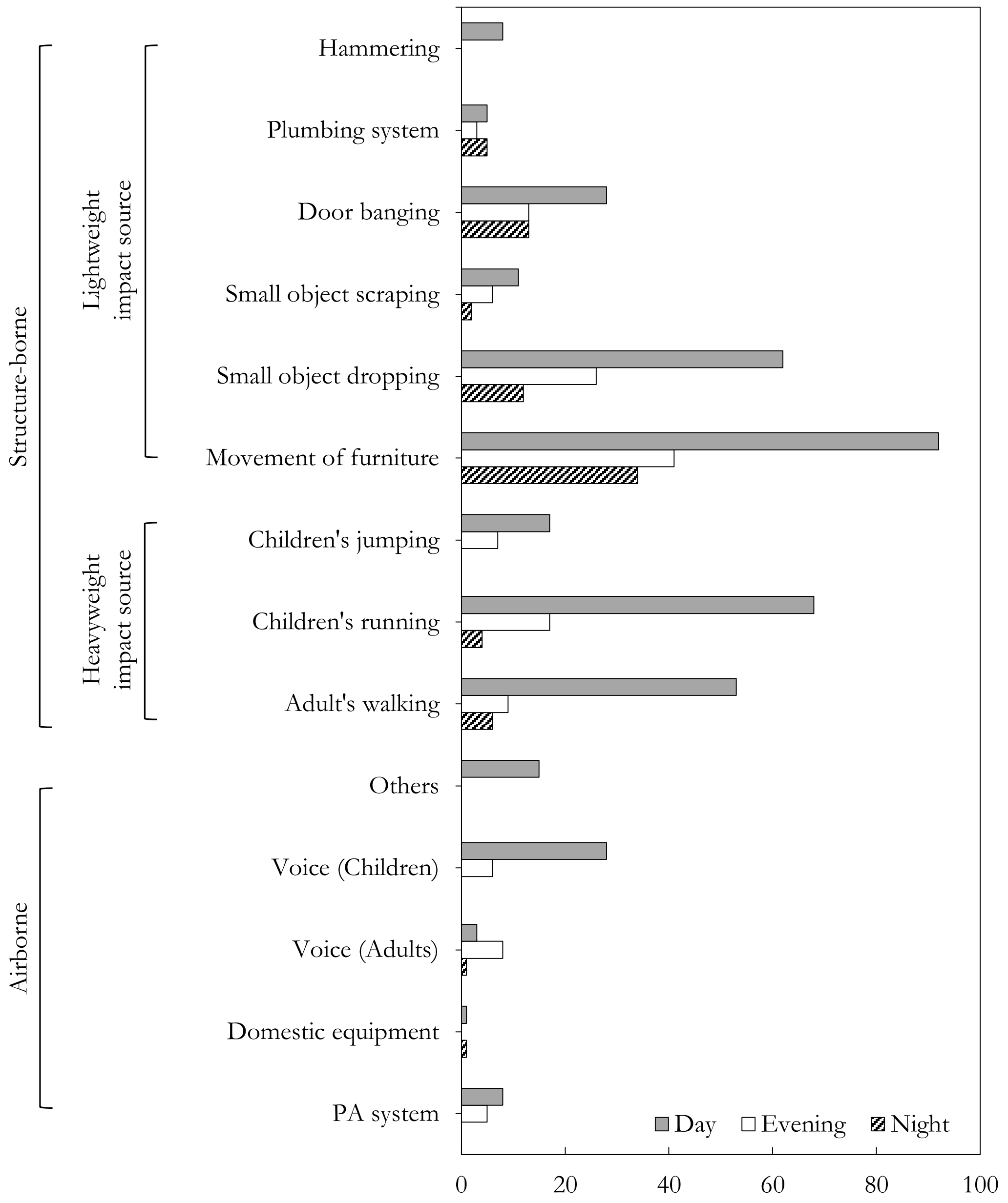


Figure 3-3. The number of occurrence of each noise source for day (grey), evening (white), and night (stripes).

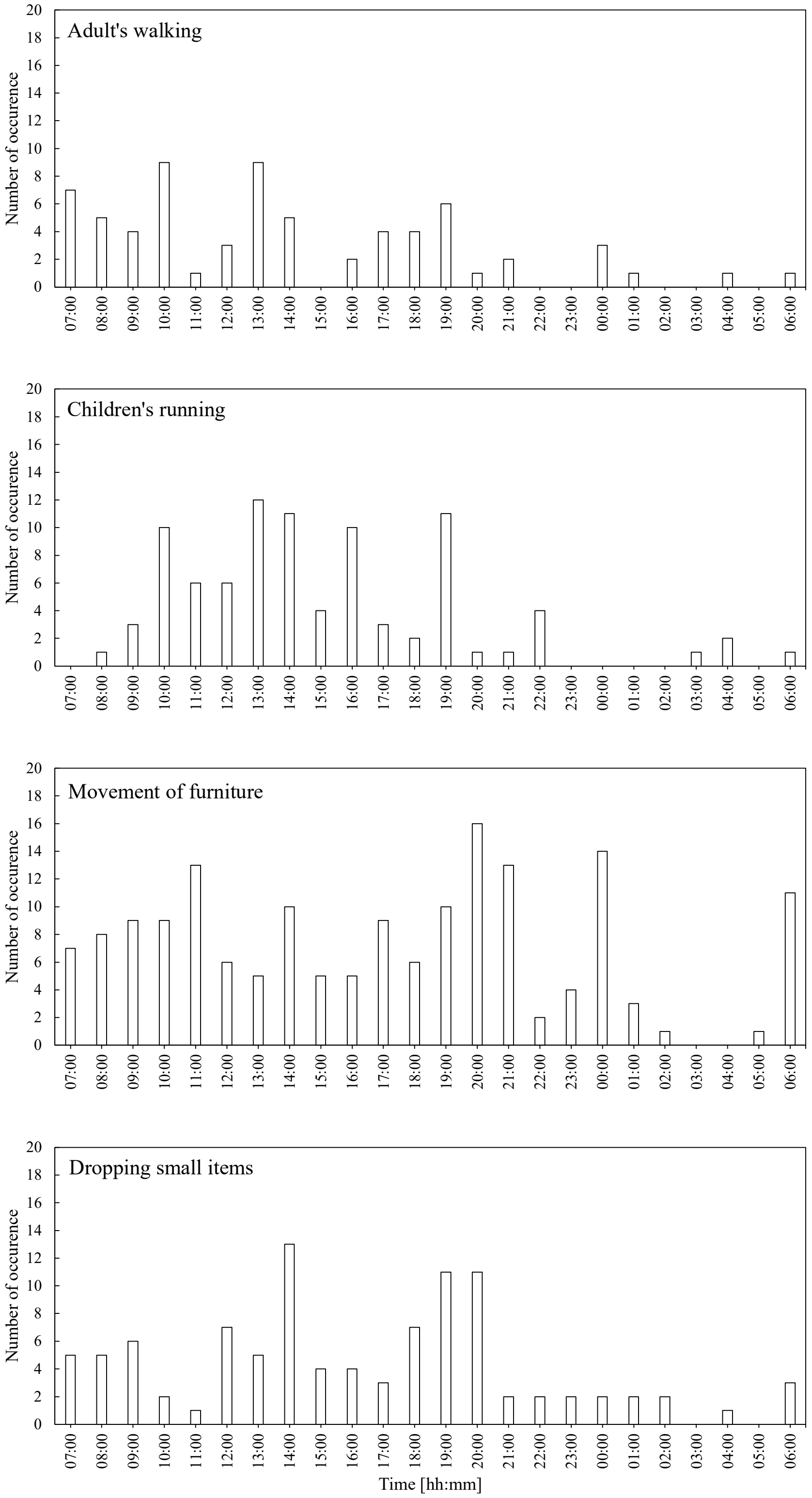


Figure 3-4. The number of occurrence of the four major noise sources at hourly intervals for 24 hours.

There were four major noise sources which accounted for large proportions: adults' walking, children's running, movement of furniture, and dropping of small objects. Figure 3-4 presents the number of occurrence of the four sources at hourly intervals. Adults' walking frequently occurred between 07:00 and 10:00. This could be because it is time for getting ready to go to work, helping their children to go to school, or doing household chores. Movement of furniture also occurred frequently during these times. Noise such as scraping of chairs in these times can be regarded as people upstairs were having breakfast. Children's running started to be frequent from 10:00 and the other three noises became frequent around 13:00 ~ 14:00. It can be said that all the four noises were closely related to each other, which could be primarily related to children's activities. In particular, it was identified that children's running noise during the afternoon occurred more frequently with scraping noise of chairs and dropping or scraping noise of small objects. Movement of furniture was exposed with a relatively large number of occurrence in the evening (19:00 ~ 20:00) and at night (23:00 ~ 00:00). These noise events might be relevant to people's activities after coming back from work, for example, such as having dinner or resting.

3.3.3 Lengths of each noise source

The lengths of the noise sources are described in Figure 3-5 and Table 3-7. The shortest noise events were the adult's walking, the movement of furniture, and the dropping of small objects (1.3 seconds). The median length of the adult's walking was 18.4 seconds, that of the movement of furniture was 6.3 seconds, and that of the dropping of small objects was 5.5 seconds. The longest noise event was children's running (1,683 seconds). The median length of the children's running was 31 seconds. The shortest median and mean lengths were caused by the door banging. The longest median and mean lengths were generated by the plumbing system. Given that this study only examined noise events exceeding the threshold noise levels, it was assumed that the actual noise events would last for longer.

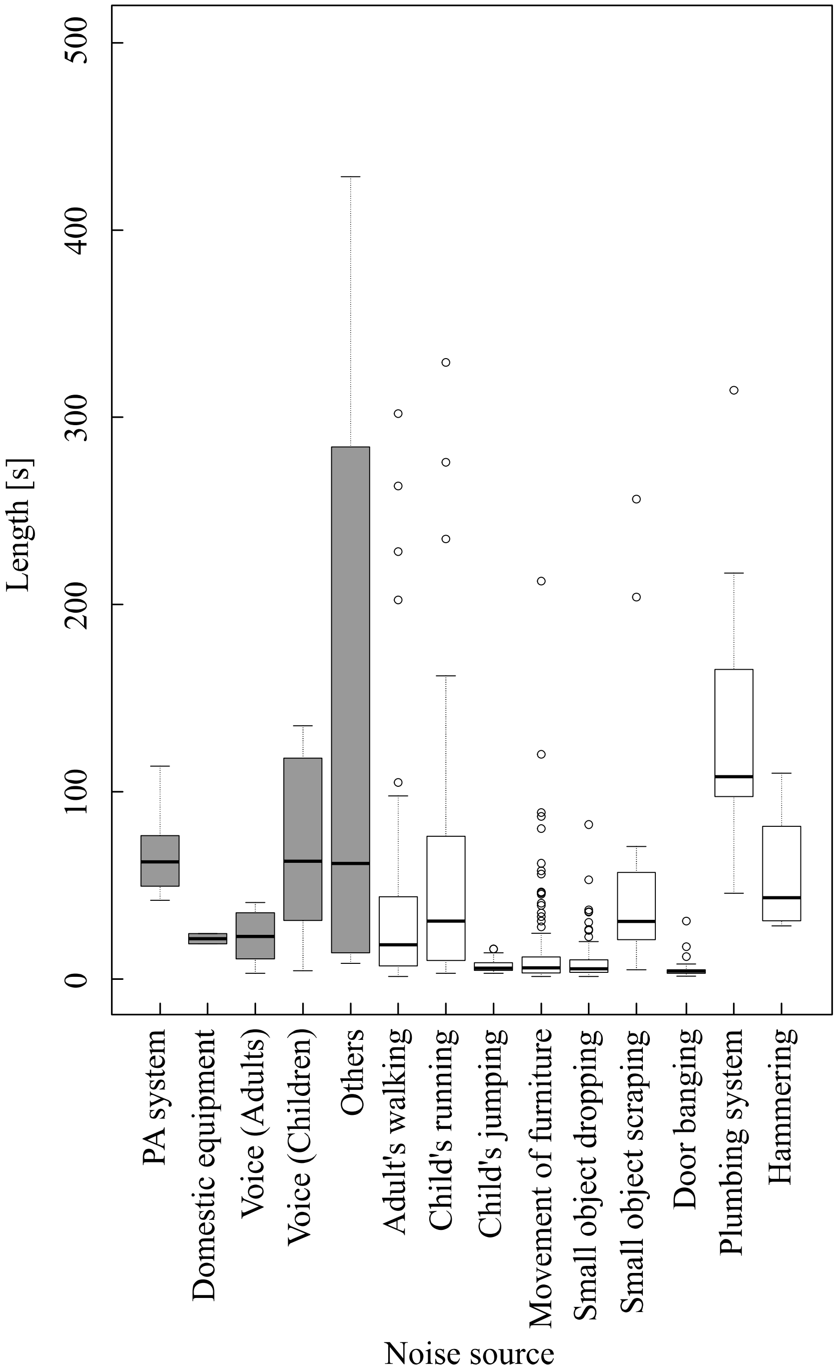


Figure 3-5. Lengths of each noise source; the airborne noise sources are shown with grey boxes and the structure-borne noise sources are shown with white boxes.

Table 3-7. Lengths of each noise source.

Noise source			*Mdn*	*M*	*SD*	*Min*	*Max*
Airborne	PA system		62.5	66.7	23.5	42.0	113.8
	Domestic equipment (e.g. vacuum machine)		21.5	21.5	3.9	18.8	24.3
	Voice	Adults	22.8	87.2	190.1	3.0	556.8
		Children	63.0	122.3	235.5	4.5	1,020.0
	Others (e.g. musical instrument)		61.8	144.6	168.2	8.3	428.5
Structure-borne	Heavyweight impact	Adult's walking	18.4	40.4	62.3	1.3	302.0
		Children's running	31.0	103.7	251.1	3.0	1,683.0
		Children's jumping	5.9	7.3	4.0	3.0	16.0
	Lightweight impact	Movement of furniture	6.3	13.2	23.4	1.3	212.5
		Small object dropping	5.5	9.4	11.7	1.3	82.5
		Small object scraping	30.8	56.3	69.3	5.0	256.3
		Door banging	4.3	5.0	4.4	1.5	31.0
		Plumbing system	108.0	142.0	91.9	45.8	314.5
		Hammering	43.4	56.3	37.4	28.3	110.0

3.3.4 Noise levels of each noise source

Figures 3-6 and 3-7 show the box-plots of the noise levels of each noise source in terms of L_{AFmax} and L_{AE}, respectively. L_{Aeq} was not appropriate to describe the noise levels of each source because there were large variations in the lengths of the noise sources. Thus, L_{AE} was adopted to describe the noise levels of each source. In general, airborne noise sources presented larger variations than structure-borne sources. Among the airborne noise sources, the noise from the PA system showed the highest median values followed by the voice of children. However, the PA system was not frequently heard (Table 3-6). In addition, it is questionable that the PA system could be regarded as one of the neighbour noise sources because it is literally the public address system which the whole residents in the building are exposed to at the same time. Among the structure-borne sources, hammering and door banging produced the highest and lowest medians of L_{AE}, respectively. Although plumbing system showed the lowest L_{AFmax} (Figure 3-6), it was the second highest in terms of L_{AE} (Figure 3-7) since it had the longest length (Table 3-7 and Figure 3-5) and the length should be applied to derive L_{AE}. All the median L_{AE} of adults' walking, children's jumping, movement of furniture, and dropping of small objects were similar and children's running and scraping of small objects had relatively higher median L_{AE}. Particularly, these two noise sources had higher median L_{AE} than other structure-borne noises (except hammering) since they lasted longer than the others.

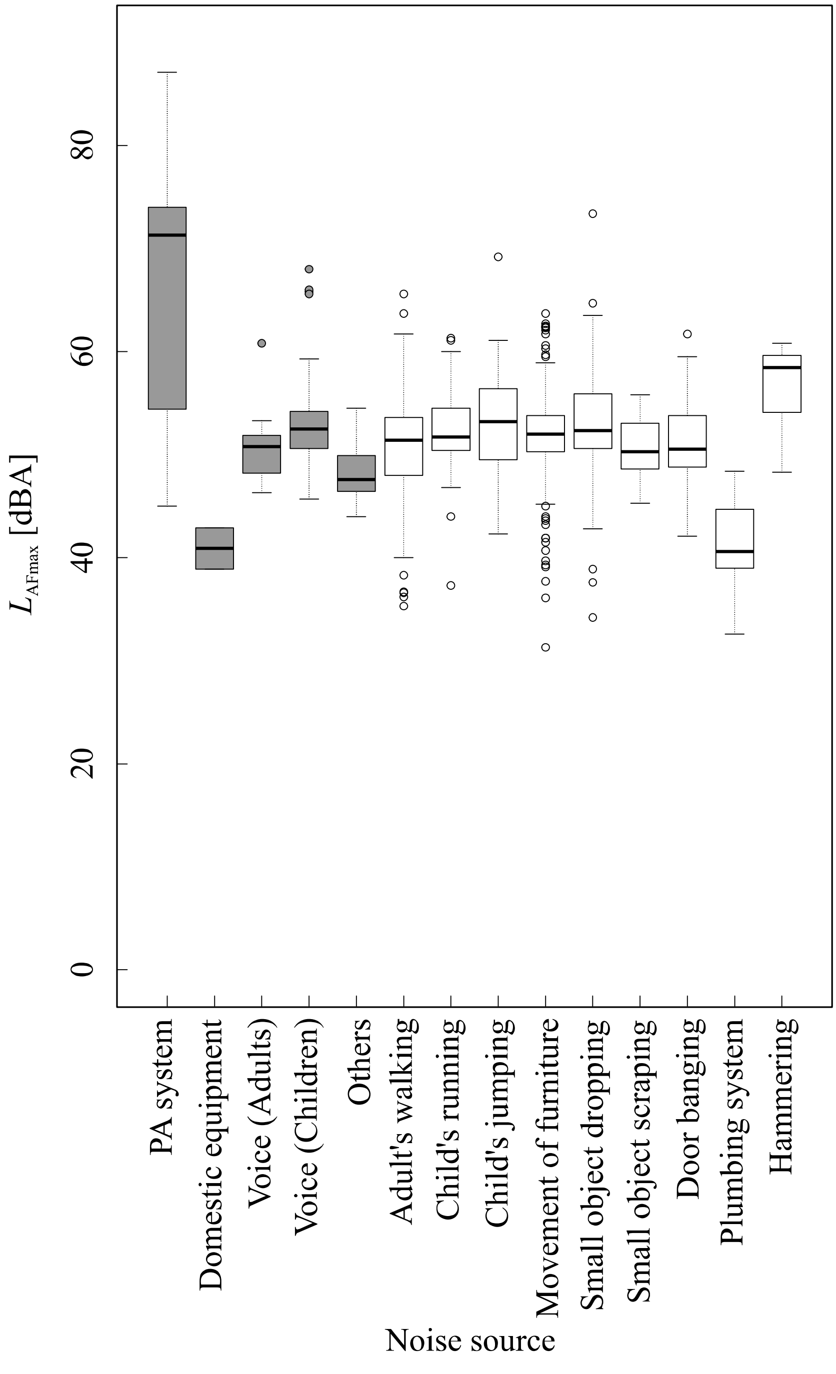


Figure 3-6. L_{AFmax} for the noise sources; the airborne noise sources are shown with grey boxes and the structure-borne noise sources are shown with white boxes.

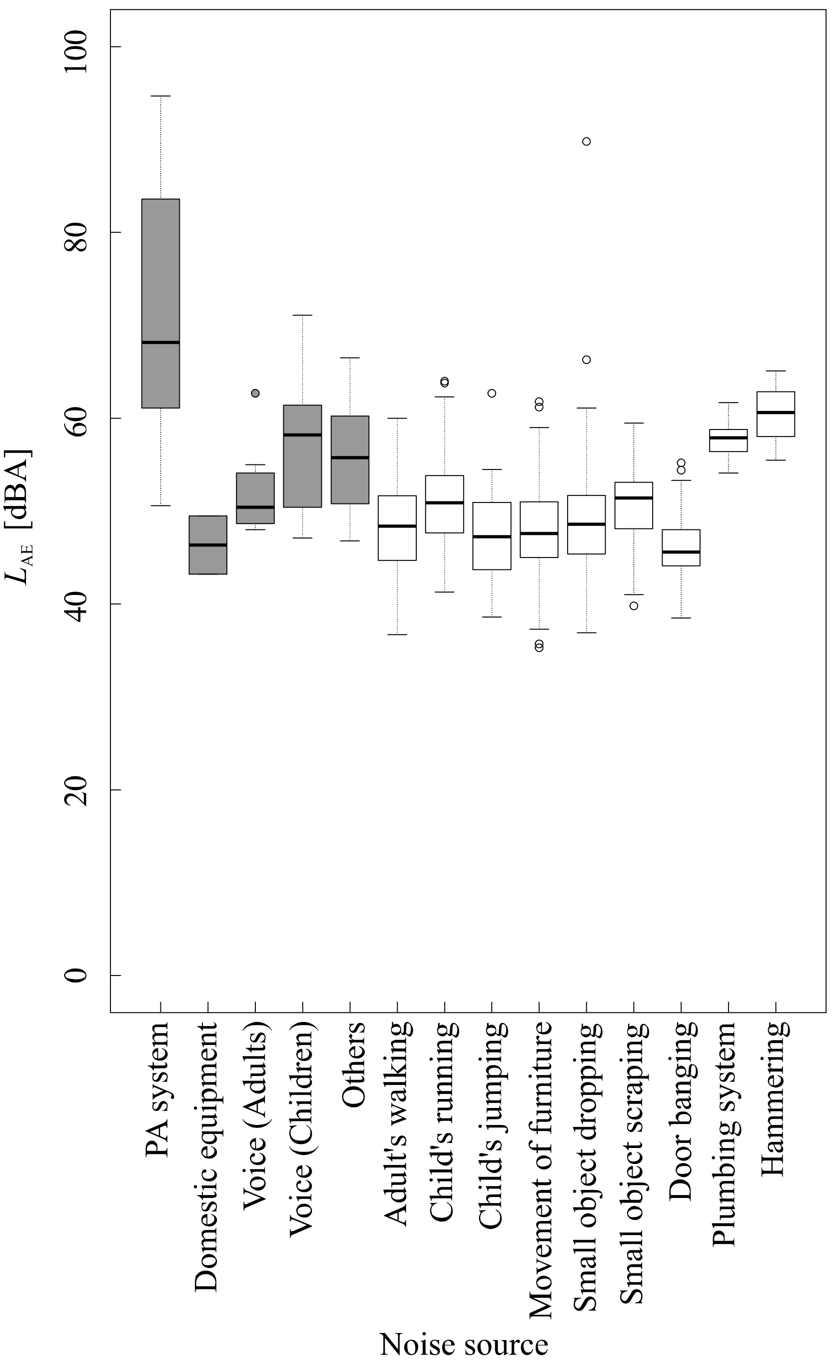


Figure 3-7. L_{AE} for the noise sources; the airborne noise sources are shown with grey boxes and the structure-borne noise sources are shown with white boxes.

3.3.5 Relationships between the variables

There were four different thicknesses of slabs being used in different sites. The noise levels and the number of occurrence were compared between the different slab thicknesses. Table 3-8 lists median values of noise levels (L_{Aeq} and L_{AFmax}) across the different slab thicknesses. The noise levels are listed for different time periods. The highest L_{Aeq} for 24 hours was from 210 mm and the lowest was from 180 mm. The highest L_{AFmax} for 24 hours was from 180 mm and the lowest was from 135 mm. Figures 3-8 shows L_{Aeq} for different time periods across the different slab thicknesses. Figures 3-9 presents the number of occurrence of different noise sources across the different slab thicknesses. The slab thickness did not have any correlation with the noise levels and the number of occurrence. There was also no correlation between the year of construction and the noise levels or the number of occurrence.

Table 3-8. Median L_{Aeq} and L_{AFmax} across the different slab thicknesses.

		Slab thickness [mm]			
		135	150	180	210
Noise level [dBA]	$L_{\mathrm{Aeq,24\text{-}hour}}$	30.1	29.3	26.3	32.9
	$L_{\mathrm{Aeq,Day}}$	30.4	30.0	27.4	33.2
	$L_{\mathrm{Aeq,Evening}}$	30.2	29.1	26.1	33.2
	$L_{\mathrm{Aeq,Night}}$	29.6	27.4	25.6	29.6
	$L_{\mathrm{AFmax,24\text{-}hour}}$	53.7	57.7	61.5	60.8
	$L_{\mathrm{AFmax,Day}}$	52.7	57.3	61.5	60.8
	$L_{\mathrm{AFmax,Evening}}$	53.7	55.0	49.6	52.4
	$L_{\mathrm{AFmax,Night}}$	49.7	50.6	49.7	48.5

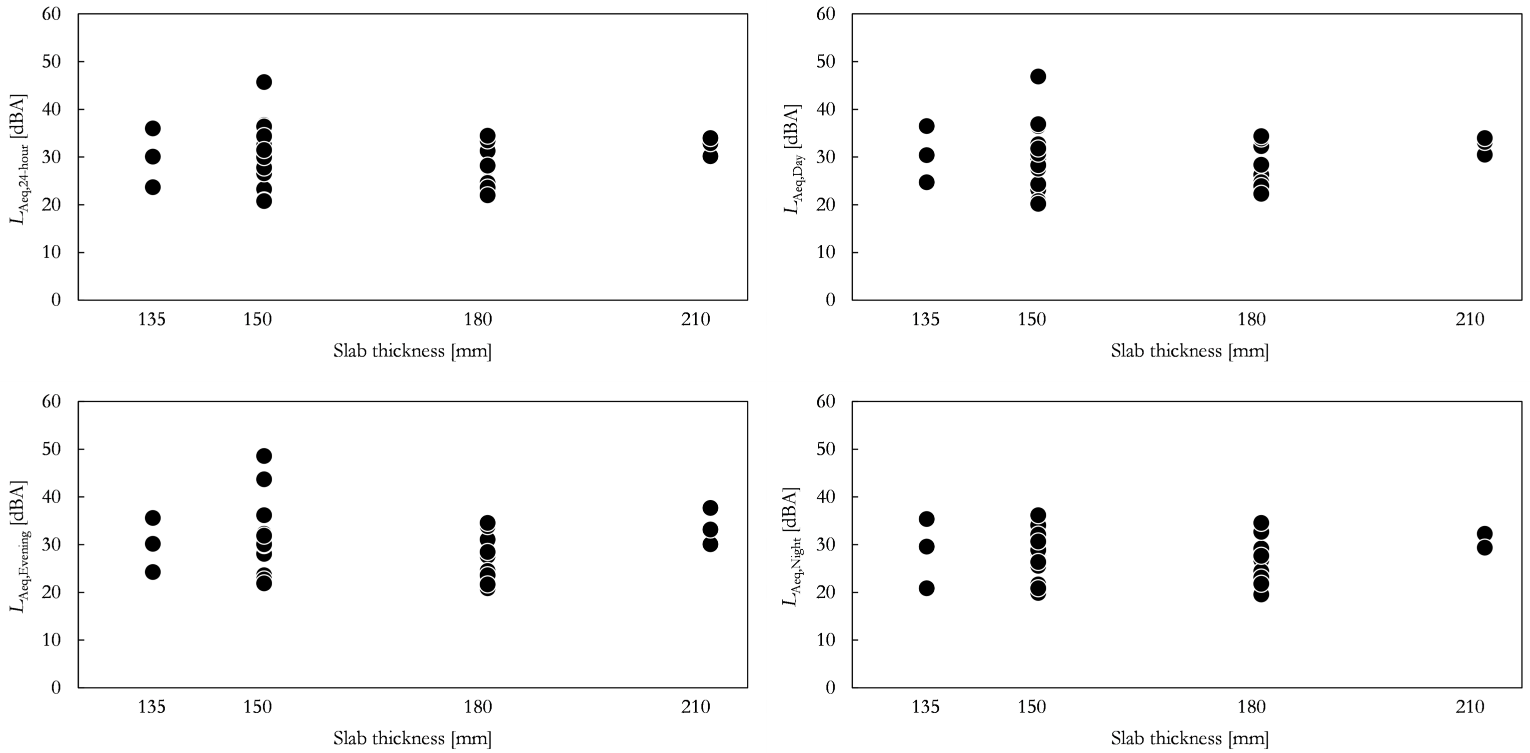


Figure 3-8. Relationships between the slab thickness and L_{Aeq} for 24-hour, day, evening, and night.

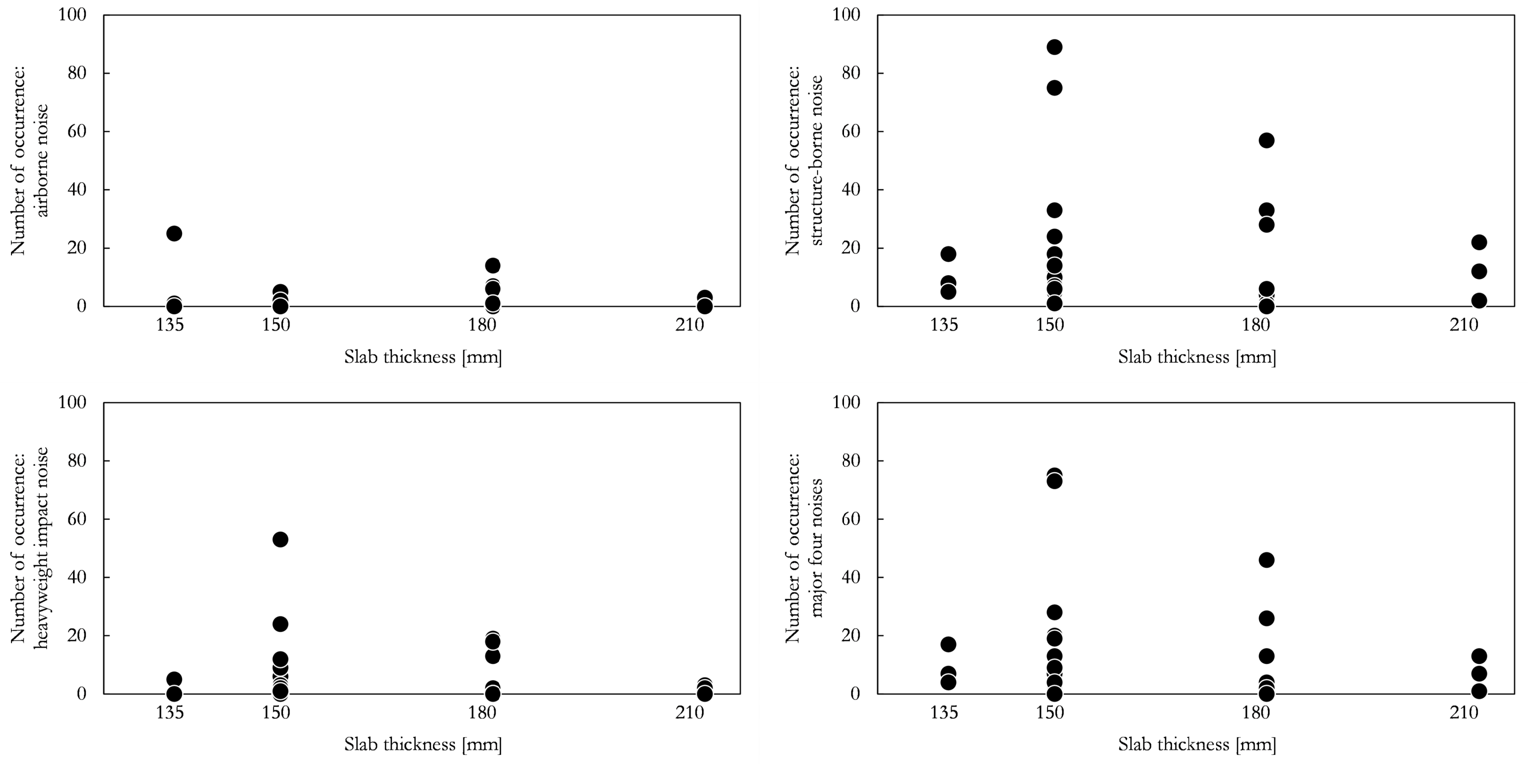


Figure 3-9. Relationships between the slab thickness and the number of occurrence of different noise sources: airborne, structure-borne, heavyweight impact, and the four major noises.

In order to investigate whether the indoor noise levels were affected by the number of occurrence and type of noise sources, correlation analyses were conducted. All the noise sources and the noise levels (L_{Aeq} and L_{AFmax}) for 24 hours, day, evening, and night were tested. Table 3-9 and presents correlations of the noise sources with L_{Aeq}. Only the number of occurrence of the airborne noise had a significant but not very strong correlation with L_{Aeq} at the night-time. Additionally, Table 3-10 lists correlations between the number of occurrence of each noise source and L_{Aeq}. The number of the voice of adults and children had significant but not very strong correlations with the night-time L_{Aeq}. The structure-borne noises showed no correlation with L_{Aeq}. Figure 3-10 illustrates the relationships of the number of occurrence of the structure-borne, heavyweight impact, and the four major noises with L_{Aeq} across the different slab thicknesses. There was no correlation found across the different slab thicknesses.

Table 3-9. Correlations of the number of occurrence of airborne, structure-borne, heavyweight impact, and the four major noises with L_{Aeq} for 24-hour, day, evening, and night (*$p < 0.05$).

		L_{Aeq} [dBA]			
		24-hour	Day	Evening	Night
Number of occurrence	Airborne noise	.324	.320	.271	.358*
	Structure-borne noise	.129	.201	.054	-.024
	Heavyweight impact noise	.018	.086	-.019	-.124
	Four major noises	.166	.236	.078	.003

Table 3-10. Correlations between the number of occurrence of each noise source and L_{Aeq} for 24-hour, day, evening, and night (* $p < 0.05$).

		L_{Aeq} [dBA]			
		24-hour	Day	Evening	Night
Airborne	PA system	.388*	.299	.420*	.148
	Domestic equipment	.066	.088	.044	.073
	Adults' voice	.285	.260	.272	.367*
	Children's voice	.265	.265	.223	.363*
	Others	-.050	.014	-.141	-.124
Structure-borne	Adults' walking	.106	.147	.097	.091
	Children's running	.032	.102	-.021	-.152
	Children's jumping	-.221	-.168	-.222	-.343
	Movement of furniture	.235	.294	.106	.069
	Small object dropping	.161	.215	.099	.052
	Small object scraping	.014	.054	.011	.002
	Door banging	-.177	-.167	-.160	-.071
	Plumbing system	.138	.176	.190	-.082
	Hammering	.118	.117	.104	.187

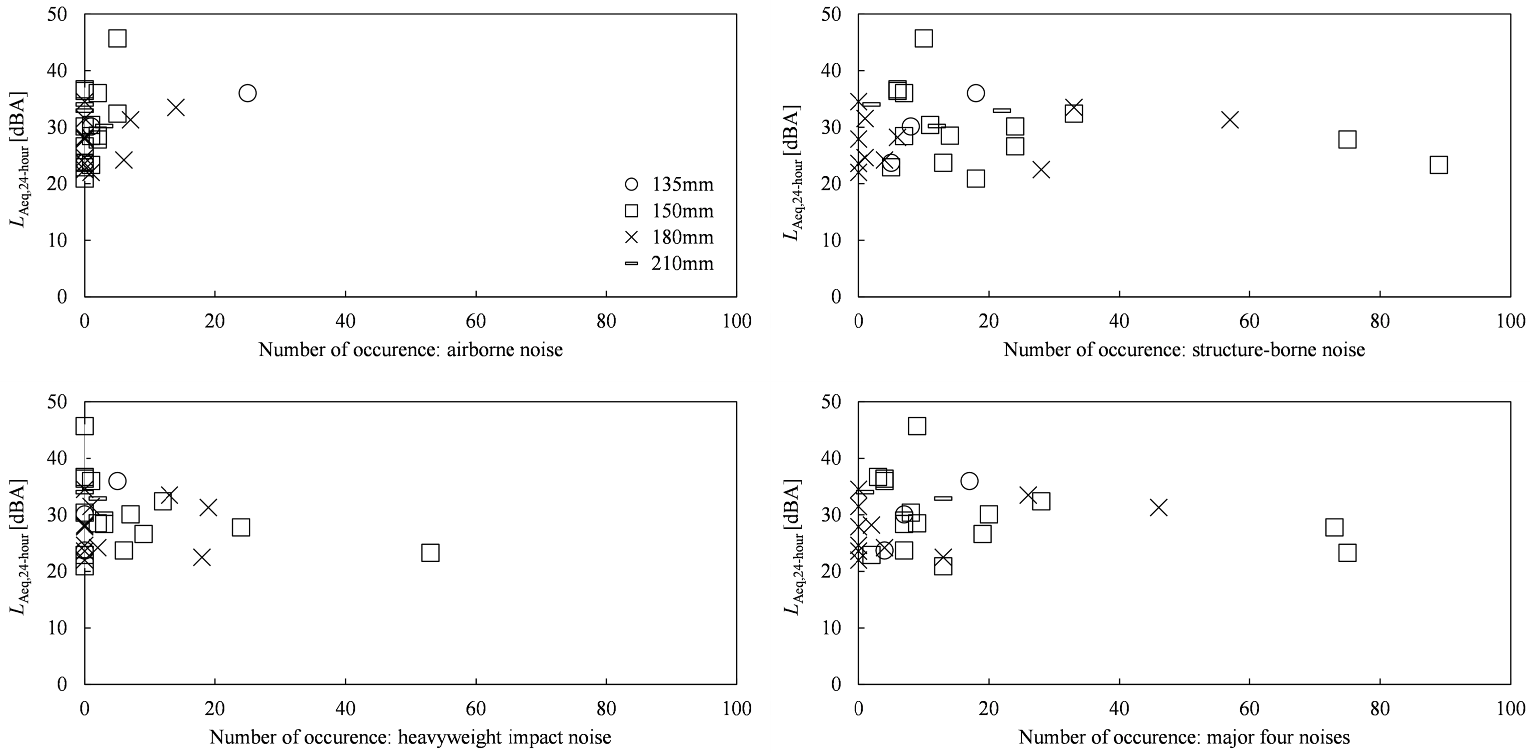


Figure 3-10. Relationships between the number of occurrence of different noise sources (airborne, structure-borne, heavyweight impact, and the four major noises) and L_{Aeq} for 24 hours across the different slab thicknesses.

3.4 Discussions

3.4.1 Noise levels

Acoustic comfort is one of the important parameters for indoor environment quality (Lai and Yik, 2009; Frontczak et al., 2012). It would be one of the crucial conditions for the pleasant indoor soundscape (Berglund and Nilsson, 2006). Of 32 participated sites, 26 of them met the recommended L_{Aeq} of WHO guidelines during the daytime and evening. The levels at eight sites exceeded the WHO recommendation during the night. It does not indicate that the noise levels were acceptable and provided acoustic comfort because the impact of outdoor noise sources was very limited because all windows were closed. The overall noise levels found in this study had a good agreement with Jeon et al. (2007) when they measured noise levels at empty sites with closed windows. However, a significant increase of the indoor noise levels is expected when properties are occupied or windows are open (Jeon et al., 2007; Lai et al., 2009; Pujol et al., 2012). The WHO guideline also recommends that L_{AFmax} should not exceed 45 dBA at night. It was observed that only five sites showed lower levels than this limit. Thus, it could be assumed that the residents in the other 27 sites might have experienced sleep disturbance at night. Most of the L_{AFmax} at night were produced by movements of furniture between 23:00 and 00:00 and early in the morning between 05:00 and 07:00. This finding supported a previous study presenting that residents in multi-family housing frequently complained about noise coming from upstairs early in the morning and late night (Park et al., 2016a). The study also found that the noise levels showed large variations across the participated sites. The L_{Aeq} for 24 hours varied from 20.8 to 45.7 dBA. Moreover, the difference between the lowest and highest levels of L_{AFmax} was 43.8 dB in the evening. Therefore, it can be interpreted that the noise levels in the sites were significantly affected by neighbours and their activities.

3.4.2 Noise sources

This study reported that the dominant noise sources in the sites were human footsteps, movement of furniture, and dropping of small objects. On the other hand, surveys in European countries have reported quite different findings. A survey in the UK (Department for Environment Food and Rural Affairs, 2015) reported that the most annoying neighbour noise sources were airborne sources such as voices, dogs, and radio/television, whereas the percentage of neighbours' footsteps and banging on walls or floors accounted for less than 10 %. Another survey conducted in the Netherlands reported that the most commonly heard noise from neighbours was flushing noise from toilets and the most annoying noise was playing music followed by radio/television and footsteps (van Dongen, 2001). The difference between the aforementioned European studies and this study could be attributed to the dwelling types in which the respondents lived. For instance, in the British study, the majority of the respondents lived in semi-detached, detached, or terrace houses, whereas only 13 % of them lived in either flats or maisonettes (Department for Environment Food and Rural Affairs, 2015). However, all the sites which took part in this study were multi-storey heavyweight buildings. A recent study on loudness and annoyance of neighbour noise in residential buildings also reported that subjective ratings varied across housing types (Wang et al., 2015).

3.4.3 Slab thickness

Previously, impact sound insulation of floors has been reported to be improved with the increase of concrete slabs (Jeon et al., 2006b; Huang, 2014). However, these previous measurements were mostly conducted in experimental settings where the standard impact sources (e.g. an impact ball and a tapping machine) were used and the noise levels in real situations were not applied. This study compared the characteristics of noise exposure between the different slab thicknesses but there was no significant influence of the slab thickness found. Therefore, a different approach needs to be considered to enhance acoustic comfort in residences. For instance, non-acoustic factors need to be considered when it comes to evaluating subjective impressions towards indoor building noise. Recent studies have reported a few non-acoustic factors affecting subjective reactions to floor impact noise such as noise sensitivity (Ryu and Jeon, 2011; Park et al., 2016a; Park et al., 2016b). It was also reported that residents who had more positive relationships with neighbours expressed less noise annoyance (Park et al., 2016a). Therefore, it implies that noise annoyance could be reduced by dealing with non-acoustic and non-technical factors.

3.4.4 General discussion

Most auditory experiments have applied the same noise level variations to different noise sources. For example, Jeon et al. (2010b) reported annoyance ratings of two drainages (a bathtub draining and a flushed toilet) and two airborne noises (conversation and piano) with the same noise level variations. Ryu and Jeon (2011) also investigated noise annoyance caused by five airborne sources (conversation, piano, telephone ringing, music, and television) with the same noise variation of 30 to 50 dBA. However, this study revealed that the noise levels were different across all noise sources. Therefore, this finding provided practical ideas for future research design, in particular, for auditory experiments which will use neighbour noise stimuli. Further, 27 of the 32 measurements were conducted between June and September during which the weather was warm enough for residents to leave their windows open in the daytime. Under such conditions, the noise levels of airborne noise from neighbours' houses might have been greater than those in other seasons of the year when residents normally close the windows. Additionally, the measurements which were performed during the school term-time (March ~ July; September ~ December) might have shown limited noise events caused by children's activities. Therefore, longitudinal measurements would be beneficial in future to cover all seasons of the year. Furthermore, this study did not evaluate the subjective responses of the occupants of the sites. It has been common to report dose-response functions based on 24-hour noise levels and subjective ratings in the environmental noise research fields, but there has been no attempt presenting such a relationship in the indoor noise research field, especially as to the noise from neighbours. Therefore, valuable data would be yielded if future research conducts both field measurements and questionnaire surveys in residential buildings.

3.5 Summary

The on-site noise measurements were carried out for 24 hours in 32 residences in multi-family housing. The recordings were analysed at 1-minute intervals in terms of L_{Aeq} and L_{AFmax} for three different time periods (day, evening, and night). As to the WHO recommended L_{Aeq}, most of the sites met the recommended levels. However, most of the sites exceeded the limits when the L_{AFmax} limits were considered. Human footsteps (both adults' and children's), movement of furniture, and dropping of small objects were the major sources in terms of the number of occurrence. Except for the hammering noise, L_{AFmax} of children's jumping and dropping small objects were greater than other structure-borne noises. Moreover, the noise level was not affected by the slab thickness or the number of occurrence. Although the findings from this study cannot fully represent the whole population, they would be of help for future research, particularly those which will be conducted in laboratory settings, to design noise stimuli based on the characteristics (e.g. noise levels of each source) found in this study. Table 3-11 lists the summary of the major findings of this study with the research question of the study.

Table 3-11. The research question and the findings of this study.

Research question	Findings
▪ What kinds of indoor noise would be heard in real residences in heavyweight multi-family housing buildings?	▪ Noise level - L_{Aeq}: 20.8 ~ 45.7 dBA (24-hour) - L_{AFmax}: 48.8 ~ 87.1 dBA (24-hour) - The highest and lowest L_{AFmax} of structure-borne noise sources were made by hammering and plumbing system, respectively. The noise level of the plumbing system considerably increased when L_{AE} was derived because of its long length. ▪ Noise source - Airborne: PA system, domestic equipment, adult's voice, children's voice, and others. - Structure-borne: adult's walking, children's running, children's jumping, movement of furniture, small object dropping, small object scraping, door banging, plumbing system, and hammering. ▪ Number of occurrence - Dominant sources: adult's walking, children's running, movement of furniture, and dropping of small objects. ▪ Noise length - The whole noise sources lasted ranging from 1.3 to 1,683 seconds. - The dominant sources' median lengths ranged from 5.5 to 31 seconds. ▪ The slab thickness did not correlate with the noise characteristics, implying that other physical characteristics, as well as neighbours' activities, are important determinants for the indoor noise events.

4 Psychological and physiological responses to floor impact noise: A laboratory study[*]

4.1 Introduction

The previous study in Chapter 3 found the noise events exceeded the L_{AFmax} limits from most of the participated sites. The noise events exceeding the noise level limits were likely to have impacts on the occupants' annoyance as well as sleep at night. Annoyance and sleep disturbance have been widely known to be related to individuals' health risks. So far, subjective perceptions of floor impact noise have been evaluated in several studies mainly by using questionnaire surveys but there is little knowledge about physiological reactions to the noise. This study examined psychological and physiological responses evoked by floor impact noise stimuli. It was carried out in a laboratory setting in which two psychological responses (annoyance and noticeability) and three physiological measures (heart rate, electrodermal activity, and respiration rate) were investigated. A total of 21 participants took part in the experiment. During the measurements, the

---

[*] This chapter has been partly published in a peer-reviewed journal and a conference proceeding. The papers can be found in Appendix 7.

participants were exposed to floor impact noise stimuli generated by either real impact sources (e.g. footsteps and scraping of furniture) or the standard impact source (impact ball). Each noise source was presented at different ranges of noise levels. The study was conducted based on the following research questions and objectives as shown in Table 4-1.

Table 4-1. The research questions and objectives of the present laboratory study.

Research questions	Objectives
▪ How do people respond to floor impact noise psychologically and physiologically?	▪ To investigate psychological responses to floor impact noise: noticeability and annoyance. ▪ To investigate physiological responses to floor impact noise: heart rate, electrodermal activity, and respiration rate.
▪ What factors have impacts on the responses?	▪ To investigate the impacts of the following factors on the responses: - Noise level - Type of noise source (real and standard impact noises)

4.2 Methods

4.2.1 Participants

Twenty-one Korean participants (8 males and 13 females) took part in the study. Age of the participants ranged from 18 to 42 (*M* = 29.5, *SD* = 6.6). Seven participants were married and six of them had one or more children. Of these participants, 13 reported that they had experienced being exposed to noise from their upstairs neighbours. None of the participants had hearing disabilities.

4.2.2 Noise stimuli

A total of six different noise sources were used to represent a majority of the impact noises in residential buildings in the previous study (Chapter 3). Five real sources were used with a standard heavyweight impact source (impact ball) adopted in ISO 10140-5. The real sources were classified into two groups based on their physical characteristics; (1) heavyweight impact sources and (2) lightweight impact sources. The heavyweight impact sources included human footsteps, such as an adult walking barefoot, a child running, and jumping barefoot. The lightweight impact sources were the dropping of a toy (0.5 kg) and the scraping of a chair. Walking footsteps of a male adult participant with a weight of 70.1 kg and a height of 170.6 cm and running and jumping noises of a seven years old child with a weight of 24.1 kg were chosen for the footstep noises. The dropping height of the impact ball and the toy was 1 m. Noise recordings were conducted in a test building which was designed to simulate the living rooms of residential buildings in South Korea. Background noise level inside the test building was approximately 25 dBA. The floor layer of the building consisted of a 210 mm thick concrete slab, a 30 mm thick resilient material, a 40 mm thick lightweight concrete, and 40 mm thick mortar. All the rooms were furnished and wooden flooring was installed as a finishing material. The shape of the room was rectangular (4.5 m × 3.5 m) and the volume was around 38 m^3. The noises were recorded binaurally through a head and torso simulator (Brüel & Kjær Type 4128C). The head and torso simulator was positioned on a chair of the receiving room (downstairs) and impact noises were made at the centre of the source room (upstairs). Appendix 2 shows some pictures of the noise recording. Diotic stimuli were made using only the left channel signals of the binaural recordings and were then presented to the participants in the laboratory experiment to avoid the effects of spatial characteristics on perception (Jeon et al., 2009a). Each stimulus was reproduced to be played at each noise level, and saved as a separate audio file (.wav). All sound reproduction procedures were carried out using audio editing software (Adobe Audition). The whole sound reproduction system was validated by comparing the reproduced sounds with the recorded sounds. The reproduced sounds were played with a loudspeaker (Fostex PM-1 MKII) and recorded at the point of the participant's ear using a head and torso simulator (Brüel & Kjær Type 4100) in an audiometric booth at Acoustics Research Unit, University of Liverpool. The difference between the frequency response of the reproduced sound and that of the recorded sound in the test building was within 3 dB (octave band levels, 63 Hz ~ 2,000 Hz). However, there were minor differences at 31.5 Hz because the frequency response of the loudspeaker was not flat below 50 Hz. The frequency characteristics of the stimuli are illustrated in Figure 4-1. All the stimuli had similar frequency characteristics with dominant sound pressure levels at low frequencies, especially at 63 and 125 Hz.

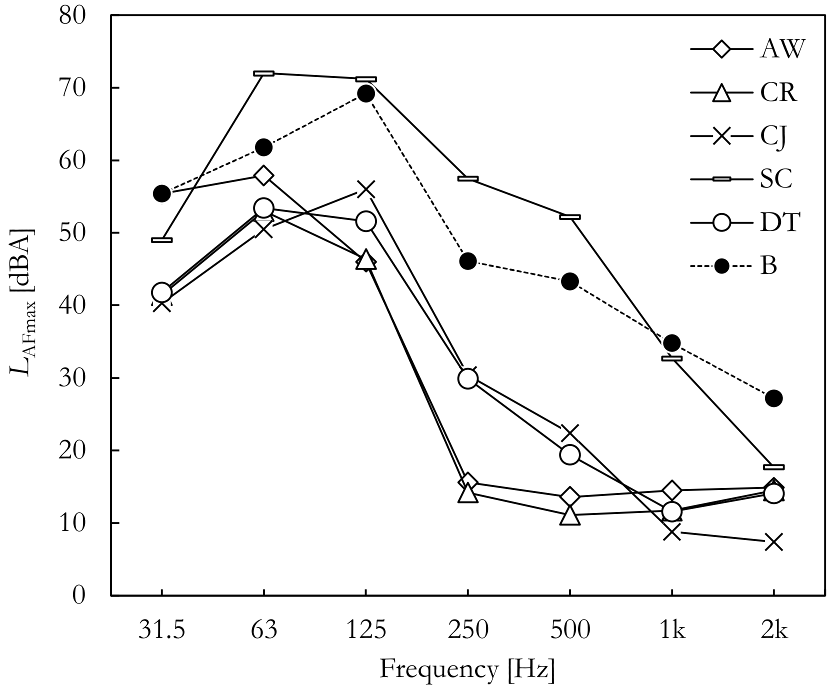


Figure 4-1. Frequency characteristics of the noise stimuli: adult's walking (AW), child's running (CR), child's jumping (CJ), scraping of a chair (SC), dropping of a toy (DT), and the impact ball (B).

As shown in Table 4-2, L_{AFmax} of the stimuli covered the noise levels ranging from 31.5 to 63 dBA in 3.5 dB intervals. The noises produced by an adult's walking and a child's running ranged from 31.5 to 45.5 dBA, and the noise of a child's jumping had a variation from 38.5 to 63.0 dBA. The dropping of a toy had a quite minor variation from 42.0 to 49.0 dBA, and the noise level of a chair scraping varied from 49.0 to 63.0 dBA. Contrary to the real impact noise, the noise generated by the impact ball was adjusted to cover a whole range from 31.5 to 63.0 dBA.

Table 4-2. The range of L_{AFmax} of the noise stimuli.

		L_{AFmax} [dBA]									
Sources		31.5	35.0	38.5	42.0	45.5	49.0	52.5	56.0	59.5	63.0
Real	Adult walking (AW)	▨	▨	▨	▨	▨					
	Child running (CR)	▨	▨	▨	▨	▨					
	Child jumping (CJ)			▨	▨	▨	▨	▨	▨	▨	▨
	Dropping of a toy (DT)				▨	▨	▨				
	Scraping of a chair (SC)						▨	▨	▨	▨	▨
Standard	Impact ball (B)	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨

4.2.3 Experimental design

The experiment consisted of five sessions. As outlined in Table 4-3, Sessions 1 ~ 4 were designed to evaluate psychological and physiological responses. Session 5 was designed to measure only annoyance ratings. In order to investigate the effect of noise level on the responses, the noise level of each source varied from 31.5 to 63.0 dBA. Sessions 1 ~ 4 lasted for around 15 minutes each and each session included 10 or 11 noise stimuli. Sessions 1 ~ 4 had varying noise levels depending on the noise sources being played in the session. Sessions 1 and 4 covered the entire range of L_{AFmax} from 31.5 to 63.0 dBA, whereas the maximum L_{AFmax} of the stimuli presented in Sessions 2 and 3 were 52.5 and 42.0 dBA, respectively. Consequently, the participants were exposed to a wide range of levels in each session. L_{AE} of Sessions 1 ~ 4 ranged from 38.8 to 49.7 dBA. In order to determine whether the type of impact source affects the responses, Sessions 1 ~ 3 included only the real impact noise and Session 4 contained only the standard impact noise. Annoyance was measured at the end of Sessions 1 ~ 4. As mentioned earlier, Session 5 was designed to particularly measure annoyance to each stimulus. Unlike the other sessions, Session 5 lasted for around seven minutes presenting all the stimuli used in the whole experiment, and the noise levels of the stimuli covered the whole range from 31.5 to 63.0 dBA. All the stimuli in Sessions 1 ~ 4 lasted for 23 seconds and were spaced at equal intervals of 50-second silence. For physiological measurements, the first and last two-minute silence periods were allocated in each session for resting time. The stimuli in Session 5 lasted for eight seconds as it was believed that there would be no significant difference between the noise annoyance ratings of stimuli with different lengths (Little and Mabry, 1969; Poulsen, 1991).

The stimuli were played in a randomised order to minimise the order effects (Jennings and Gianaros, 2007). In each session, the stimuli were presented via a loudspeaker (Fostex PM-1 MKII). Ambient noise was played throughout the experiment, emanating from another loudspeaker (Fostex PM-1 MKII). The ambient noise was equalised to have a spectrum shape of the noise criterion curve (NC-35) to mimic typical ventilation noise. Both loudspeakers were located in front of the listener at 2 m distance. A three-minute interval was given between the sessions not just to avoid any possible carryover effects between sessions but also to give the participants time to rate the annoyance of each session.

Table 4-3. Outline of each session.

		Session No.				
		1	2	3	4	5
Range of L_{AFmax} [dBA]		31.5 ~ 63.0	31.5 ~ 52.5	31.5 ~ 42.0	31.5 ~ 63.0	35.0 ~ 63.0
Noise stimuli	Type	Real	Real	Real	Standard	Real/Standard
	Number of stimuli	11	10	10	10	33
	Source	AW CR CJ SC DT	AW CR CJ SC DT	AW CR CJ DT	B	AW CR CJ SC DT B
L_{AE} of the session [dBA]		49.7	43.1	38.8	46.8	52.8
Duration of the session [minutes]		16.6	15.3	15.3	15.3	7.3
Measurements	Psychological responses	Noticeability of each stimulus; Annoyance of the session				Annoyance of each stimulus
	Physiological responses	Heart rate (HR); Electrodermal activity (EDA); Respiration rate (RR)				-

4.2.4 Response measurements

Psychological responses were assessed in terms of noticeability and annoyance. Earlier in Chapter 2, the figure illustrating the stress responses to noise (Figure 2-3) described that the noise exposure is subjectively judged in the phase of primary appraisal once the noise is 'noticed'. A few previous studies have examined noticeability of noise exposure and its relationship with acoustic factors (e.g. Fidell et al., 1979). As shown in Table 4-3, noticeability of noise events was evaluated in Sessions 1 ~ 4 and the participants were asked to press the response button when they heard the noise stimuli during the experiment. At the end of each of Sessions 1 ~ 4, the participants were also asked to rate their annoyance using 11-point scales (0 = *'Not at all'* to 10 = *'Extremely'*) as recommended in Fields et al. (2001) and the ISO/TS 15666. Annoyance caused by each noise stimulus was evaluated in Session 5. In contrast to Sessions 1 ~ 4, the participants evaluated the noise annoyance of each noise stimulus using a magnitude estimation technique in Session 5 (Stevens, 1972; Berglund et al., 1975). First, a reference noise (which was presented at 42 dBA in this experiment) was played to the participants at the beginning. The participants were then instructed to regard the annoyance level of the reference noise as 100. They were then asked to rate noise annoyance of each stimulus on the basis of the reference annoyance level. A training session was carried out to help participants get used to the technique.

Three physiological responses were measured for the entire duration of each session: heart rate (HR), electrodermal activity (EDA), and respiration rate (RR). All the physiological responses were measured using the MP 150 WSW digital acquisition system (BIOPAC Systems), recorded and analysed via a data acquisition/analysis software (AcqKnowledge 4.4, BIOPAC Systems). Two wireless amplifiers were placed under the desk where the participants were seated. The amplifiers received all the physiological signals via Bluetooth transmitting mode. HR was derived from the raw electrocardiograph data which were measured using three electrodes attached to the participant's right wrist and both ankles.

EDA was measured using two electrodes attached to the participant's index and middle fingers of the right hand. RR was computed from the raw respiration data which were measured with a respiration transducer belt worn around the chest. The respiration transducer belt records respiration data by measuring the changes in thoracic circumference that occur when the participant breathes. Figure 4-2 describes where the electrodes and the belt were attached to the participant's body.

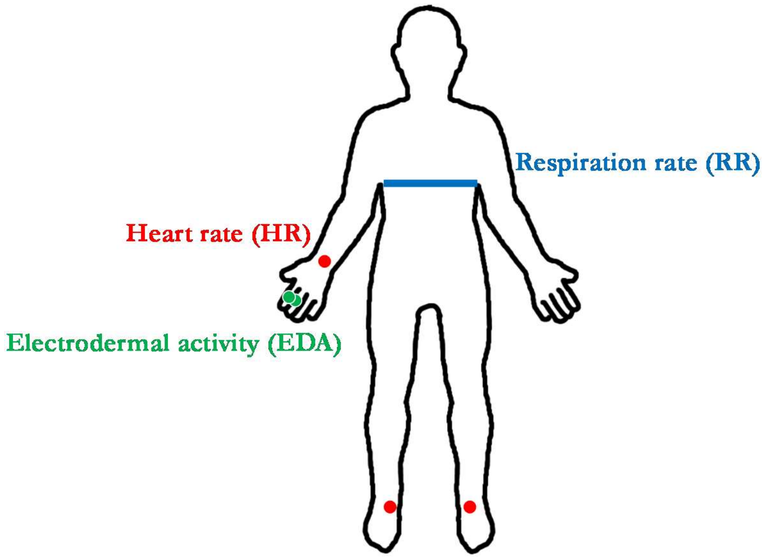


Figure 4-2. Locations from which HR, EDA, and RR signals were recorded.

4.2.5 Procedure

Only those who provided their consent participated in the study. The participants took part in the experiment individually. Each participant was asked to avoid staying up late and not to drink any alcohol or caffeinated drinks before the experiment. The participant information sheet and a written consent form were provided to the participant upon arrival. Before obtaining the consent, the author explained the purpose of the study and answered the participant's questions. The participant was assured of complete anonymity. Once all the electrodes were attached to the participant's body, the participant was then helped to be seated comfortably on a chair. A training session was first carried out in order to help the participant to get used to the environment and the measurement, as well as to check if all the measurement systems were working properly. The participant was asked to imagine that they were resting in their own home. Appendix 2 shows some pictures of the experiments. Each participant received GBP 20 gift card for the participation. The experiments were carried out in the audiometric booth at the Acoustics Research Unit. Background noise level was approximately 25 dBA.

4.2.6 Data analysis

Any erroneous data (e.g. data corrupted with movement-related artifacts) in the physiological measurements were discarded before the analysis (Schneider et al., 2003; Jennings and Gianaros, 2007). Since there could be a delay in the onset of stimulus-evoked physiological activity (Friedman and Priebe, 1998), this study only focused on analysing the responses after the delays. Thus, the physiological responses were analysed for 18 seconds excluding the first five seconds immediately after each stimulus delivery (Graham and Clifton, 1966; Dawson et al., 2007). In addition, 50 seconds of silent intervals between the stimuli were designated as baselines. Percentage changes [%] of the physiological responses were calculated derived from the changes from the baseline to noise exposure (Kaiser, 1989).

Statistical analyses were performed using SPSS for Windows (version 22). Bivariate (Pearson) correlations were assessed between two variables. Repeated measures ANOVA were tested in order to examine the effects of noise level and type of sources on the responses. The ANOVA is a statistical procedure that tests the overall fit of a linear model and tests whether group means differ to each other. Further, the repeated measures ANOVA is used when the independent variables have all been measured using the same participants in all conditions (Field, 2018). Wilcoxon signed-rank tests were carried out to assess the differences in the responses between the real and standard impact sources. Group differences were examined using the Mann-Whitney U tests and independent samples t-tests. p values of less than 5 % ($p < 0.05$) were considered as statistically significant.

4.3 Results

4.3.1 Noticeability and annoyance

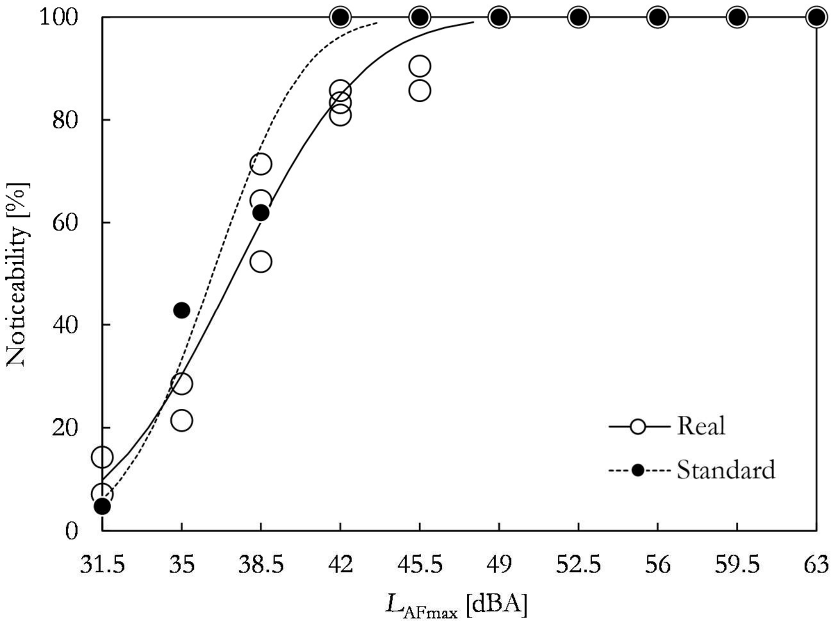


Figure 4-3. Noticeability of the real and standard impact noise stimuli as a function of L_{AFmax}.

Figure 4-3 shows the noticeability as a function of L_{AFmax} across the different sources. For both real and standard impact noise sources, the noticeability increased as the noise level increased. Correlations between noticeability and L_{AFmax} were statistically significant ($r = .62$ for the whole stimuli; $r = .61$ for the real impact noise; $r = .64$ for the standard impact noise; $p < 0.01$ for all correlations). Around 60 % of the participants noticed the noises at 38.5 dBA and the noticeability reached 100 % when the levels were equal or above 49 dBA for both the real and standard impact noise stimuli. Differences between the two impact sources were identified between 35 and 45.5 dBA and the differences gradually increased as the noise level increased. Statistically significant differences between the sources were found at two levels at 42.0 dBA ($p < 0.01$) and at 49 dBA ($p < 0.05$). The noticeability of the real impact noise also varied at the same levels depending on the noise source. For example, for noises at 38.5 dBA, the noticeability ranged from 52.4 % to 71.4 %.

This variation could be due to the differences in temporal and spectral characteristics of the noises.

Figure 4-4(a) describes the mean magnitude estimates of noise annoyance for each noise stimulus obtained from Session 5 and Figure 4-4(b) describes the mean annoyance ratings for Sessions 1 ~ 4. It was found that annoyance increased as the noise level increased for both real and standard impact noises. As Figure 4-4(a) shows, it was also observed that standard deviations also increased along with the increase of noise level for both noise sources. The annoyance ratings of the standard impact noise were consistently higher than those of the real impact noise and the statistical analysis confirmed that the differences between the two sources were statistically significant at all levels. The correlations between the annoyance ratings and L_{AFmax} were greater than 0.9 for both sources ($r = .95$ for the whole stimuli; $r = .95$ for the real impact noise; $r = .93$ for the standard impact noise; $p < 0.01$ for all correlations). The annoyance ratings of each stimulus also correlated with noticeability for both sources ($r = .47$ for the real impact noise; $r = .43$ for the standard impact noise; $p < 0.01$ for all correlations). As illustrated in Figure 4-4(b), the annoyance ratings of each session varied slightly across the sessions. The mean annoyance ratings of Sessions 1 ~ 4 were significantly different from each other ($p < 0.01$). Session 3 which contained the real impact noise with the smallest range of noise levels was rated with the lowest noise annoyance rating ($M = 4.0$, $SD = 2.3$) and it could be mainly due to the lowest L_{AE}. The highest annoyance rating ($M = 6.6$, $SD = 1.8$) was rated to Session 4 which contained the standard impact noise. The annoyance rating of Session 1 with the highest L_{AE} was slightly lower than that of Session 4, indicating that the standard impact noise evoked greater annoyance than the real impact noise. This implies that noise annoyance ratings were affected by the source type as well as the noise exposure level. There was a significant difference ($p < 0.01$) in noticeability between those who had the past experience of noise exposure ($M = 77.3$ %, $SD = 0.42$) and those who did not have any past experience ($M = 63.1$ %, $SD = 0.48$), whereas the differences in annoyance ratings between the groups were not significant.

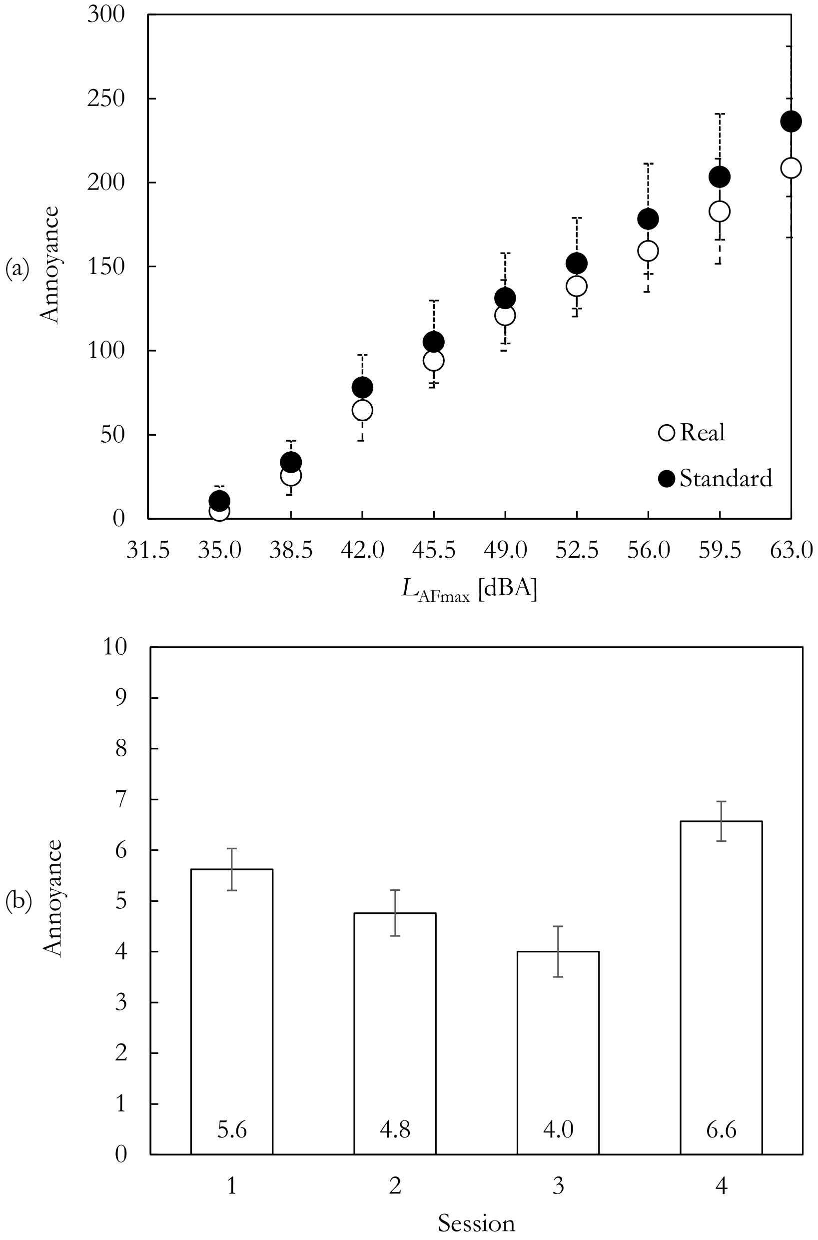


Figure 4-4. (a) Annoyance for each noise stimulus as a function of L_{AFmax} with error bars indicating standard deviations and (b) annoyance for Sessions 1 to 4 with error bars indicating standard errors.

4.3.2 Heart rate, electrodermal activity, and respiration rate

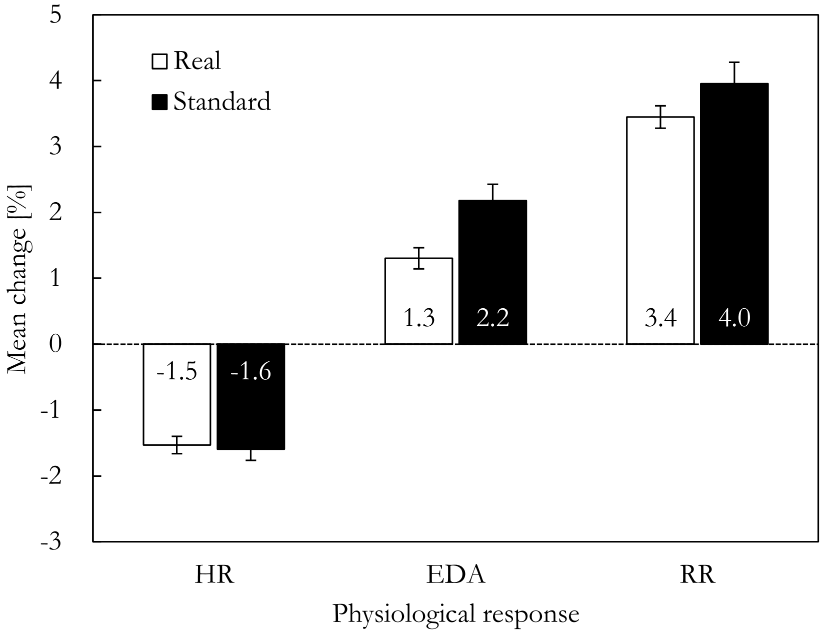


Figure 4-5. Mean percentage changes of the physiological responses during Sessions 1 to 4. Error bars indicate standard errors.

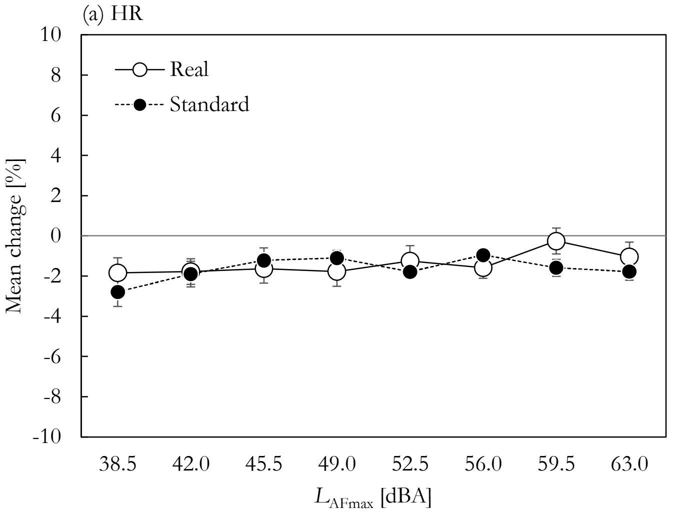
The results of the psychological assessments demonstrated that the participants hardly noticed the noise below 38.5 dBA and reported very low annoyance ratings to those stimuli. Thus, the noise stimuli at 31.5 and 35.0 dBA were excluded from analyses. Percentage changes in HR, EDA, and RR were averaged for Sessions 1 ~ 4 and the mean changes were then presented for the real and standard impact noise stimuli in Figure 4-5. The mean HR decreased by more than 1 % for both sources and the difference between the baseline and the noise exposure was statistically significant (p < 0.05). HR response to the standard impact noise decreased slightly more than that of the real impact noise but there was no significant difference between the sources. EDA increased significantly due to noise exposure (p < 0.05). The mean EDA changes were more than 2 % for the standard impact noise and 1 % for the real impact noise; the standard impact noise resulted in a higher increase than the real impact noise but the difference between the two types of the source was not statistically significant. Similarly, significant RR increases (more than 3 % for both sources) were recorded when participants listened to floor impact noise ($p < 0.05$). The RR change of the standard impact noise was higher than that of the real impact noise which can be interpreted as meaning that the participants were more sensitive to the standard impact source; however, the two changes were not statistically significant.

Table 4-4 lists the mean changes of HR, EDA, and RR as a function of L_{AFmax} which are also illustrated in Figure 4-6. Source types had no significant effect on any of the physiological responses. However, the effects of the noise level were found on EDA [F (4, 87) = 4.25, $p < 0.01$)] and RR [F (5, 96) = 4.75, $p < 0.01$)]. The interaction between the source type and noise level had no significant impact on HR and EDA but influenced RR significantly [F (5, 95) = 3.72, $p < 0.01$)].

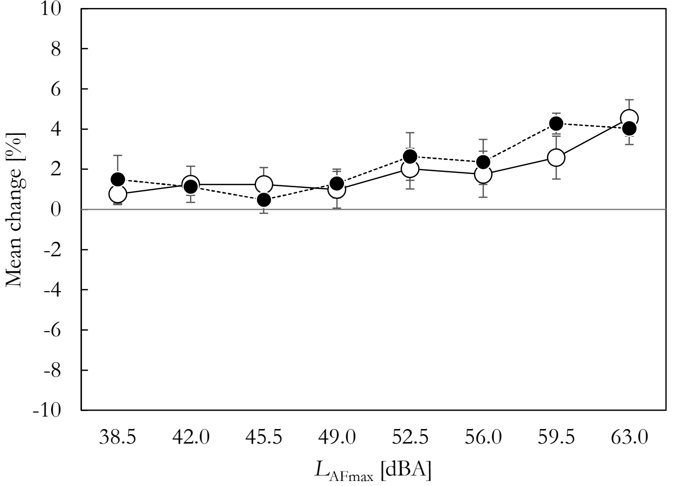
Table 4-4. Percentage changes of physiological responses at each noise level for (a) real impact noise and (b) standard impact noise.

		L_{AFmax} [dBA]							
(a) Real		38.5	42.0	45.5	49.0	52.5	56.0	59.5	63.0
HR	*Mdn* [%]	-1.47	-1.46	-0.68	-1.52	-0.86	-1.40	-0.16	-0.39
	M [%]	-1.84	-1.77	-1.63	-1.77	-1.25	-1.59	-0.26	-1.04
	SD	0.03	0.03	0.03	0.03	0.03	0.02	0.03	0.03
EDA	*Mdn* [%]	0.13	0.04	0.10	0.20	0.34	0.24	2.77	3.85
	M [%]	0.77	1.25	1.24	0.99	2.03	1.75	2.58	4.55
	SD	0.02	0.04	0.04	0.04	0.05	0.05	0.05	0.04
RR	*Mdn* [%]	3.65	2.28	4.43	2.55	2.70	5.57	2.33	4.69
	M [%]	3.62	2.94	4.44	3.04	2.90	5.45	2.88	4.31
	SD	0.03	0.04	0.04	0.04	0.02	0.03	0.03	0.03
(b) Standard									
HR	*Mdn* [%]	-2.90	-1.89	-0.41	-0.86	-1.93	-0.76	-0.91	-1.75
	M [%]	-2.79	-1.90	-1.22	-1.10	-1.79	-0.95	-1.59	-1.78
	SD	0.03	0.03	0.03	0.02	0.01	0.01	0.02	0.02
EDA	*Mdn* [%]	0.10	0.54	-0.73	0.45	1.15	0.54	4.19	3.24
	M [%]	1.49	1.13	0.48	1.29	2.64	2.36	4.28	4.04
	SD	0.05	0.02	0.03	0.03	0.05	0.05	0.02	0.04
RR	*Mdn* [%]	1.71	5.37	3.89	4.97	3.28	4.05	4.22	5.57
	M [%]	1.94	5.24	4.26	4.85	3.68	4.14	4.28	5.89
	SD	0.04	0.02	0.04	0.03	0.03	0.01	0.01	0.02

(a) HR



(b) EDA



(c) RR

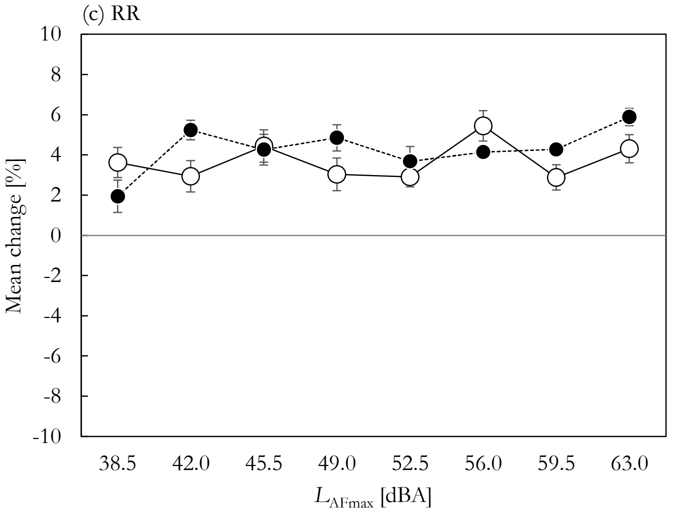


Figure 4-6. Mean percentage changes of the physiological responses as a function of L_{AFmax}. Error bars indicate standard errors.

Table 4-5 shows the correlation coefficients of the physiological responses with annoyance, noticeability, and L_{AFmax}. EDA had significant correlations with annoyance and noise level when the real impact noise was presented and with annoyance, noticeability, and noise level when the standard impact noise was presented. RR also had significant correlations with annoyance, noticeability, and noise level when the standard impact noise was presented. However, all the coefficients were not very strong. Besides, there was no significant difference in HR and EDA between those who had past experience of floor impact noise exposure and those who did not. However, there was a significant difference ($p < 0.01$) in RR between those who had been exposed to the noise in the past ($M = 3.7$ %, $SD = 0.04$) and those who had not ($M = 3.4$ %, $SD = 0.03$).

Table 4-5. Correlation coefficients of the physiological responses with annoyance, noticeability, and L_{AFmax} for (a) real impact noise and (b) standard impact noise (*$p < 0.05$, **$p < 0.01$).

(a) Real	Annoyance	Noticeability	L_{AFmax}
HR	0.06	-0.03	0.02
EDA	0.13**	0.02	0.14**
RR	0.01	0.04	0.05
(b) Standard	**Annoyance**	**Noticeability**	**L_{AFmax}**
HR	0.13	-0.12	0.03
EDA	0.23**	0.17*	0.21**
RR	0.17*	0.41**	0.31**

4.4 Discussion

4.4.1 Effects of noise level and source

Previous studies (Fidell et al., 1979; Schomer and Wagner, 1996; Sneddon et al., 2003) have reported a strong relationship between the noticeability and sound pressure levels of outdoor noises. They have also suggested that noise annoyance ratings can be explained by noticeability. This study expanded the suggestions to indoor noises, particularly to floor impact noise which is impulsive and intermittent. In this study, noticeability of floor impact noise was influenced by the noise level and noise annoyance ratings correlated with noticeability. It indicates that floor impact noise may have significant impacts on residents' subjective judgements when it is noticed. Moreover, the impact ball has been suggested as a standard impact source which has similar physical characteristics to humans in terms of mechanical impedance and impact force (Jeon et al., 2006a). The subjective impression of the impact ball noise was similar to human-caused noise (Jeon et al., 2009b). Based on these findings, the impact ball was introduced as a standard impact source in international standard to mimic human footsteps (ISO 10140-5). However, the findings of this study suggested that psychological responses (noticeability and annoyance) were significantly different between the impact ball noise and the real noises. Since the dropping noise of an impact ball in a regular interval is not familiar to the participants, the impact ball noise may have evoked significantly higher noticeability and annoyance. Park et al. (2016a) previously developed the model suggesting the relationships between noise exposure, annoyance, and health complaints. Among them, the relationship between annoyance and health complaints was validated via the survey study (Park et al., 2016b). The physiological changes found in this study provided evidence to confirm the relationship. This study also showed that the annoyance ratings of the real impact noise correlated with EDA and the annoyance of the standard impact noise correlated with EDA and RR. Besides, this study revealed that noise level affected the mean changes in EDA and RR. This implies that noise exposure has potential impacts on health problems as well as annoyance.

Lang et al. (1997) proposed a model indicating the relationship between physiological responses and arousal intensity. According to this model, people's physiological responses to the stimuli can be classified into three stages: pre-encounter, post-encounter, and circa-strike. Before the presentation of the stimuli, physiological responses such as HR and EDA are almost calm in the pre-encounter stage. HR decreases and EDA increases with an exposure to arousal stimuli during the post-encounter stage. This stage is a freezing state which involves focused attention and potentiated startle. The changes in HR and EDA occur because people's attention is oriented to the stimuli. Circa-strike is the final stage, which is an alarmed state that involves active defense and thus aims to eliminate reactions to secondary stimuli (Lang et al., 1997; Boucsein, 2012). While high arousal stimuli are presented, EDA keeps increasing, but HR changes its direction upward. A number of studies have confirmed the changes in HR and EDA in the post-encounter and circa-strike stages through laboratory experiments. Bradley and Lang (2000) found that 6-second arousing and unpleasant sounds led to significant HR deceleration. Hume and Ahtamad (2013) also reported deceleration in HR during the presentation of 8-second sound clips (i.e. post-encounter stage). On the other hand, highly arousing noise stimuli have found to evoke HR accelerations indicating the circa-strike stage. Gomez and Danuser (2004) used 30-second noise stimuli varying from 52.2 to 77.5 dBA, and Holand et al. (1999) used 0.15-second noise at 110 dBA to the participants. Regarding the changes in EDA, Tajadura-Jiménez et al. (2010) reported that unpleasant and arousing sounds resulted in the largest EDA increases. Reinhardt et al. (2012) also reported a significant increase in EDA resulting from five-minute long noise exposures ranging from 78 to 93 dBA. In this study, HR decreased and EDA increased when the noise was presented; it indicates that participants were in the post-encounter stage rather than in the circa-strike stage. This is because the noise levels presented in this study were not sufficient to lead to the high arousal status or the length of noise exposure was not long enough. This study also revealed that RR accelerated during noise exposure. This result is consistent with the findings of previous studies in which experiences of arousal or emotions (e.g. anger and fear) led to an increase in RR response. Gomez and Danuser (2004) showed accelerated breathing with decreasing pleasantness using noises ranging from 52.2 to 76.7 dBA, and Gomez et al. (2005) reported an association between arousal incurred by sounds and respiratory responses. Hume and Ahtamad (2013) also found accelerated RR with man-made noise exposures.

There are several field and laboratory studies which have addressed the associations between the noise level and physiological responses. In field studies, it has been reported that physiological responses were influenced by the noise level. Stansfeld (1992) reported a positive correlation between the noise level and EDA. Zahr and de Traversay (1994) reported significant respiratory changes in infants when the noise level was reduced by wearing earmuffs. Regecová and Kellerová (1995) also found that children living in areas with high levels of traffic noise (> 60 dBA) showed lower HR than those in quiet areas. Moreover, Babisch et al. (2013) identified significant relationships between transportation noise levels and hypertension. However, a recent laboratory study (Hume and Ahtamad, 2013) came to the opposite conclusion. The sound pressure levels of 8-second stimuli did not correlate with physiological responses (heart rate, respiration rate, and forehead electromyography). This study revealed that the noise level had impacts on EDA and RR, whereas the relationship between HR and the noise level was not significant. The inconsistency between the field and laboratory studies may be due to the different durations of noise exposure. Contrary to the field studies dealing with long-term noise exposure (Zahr and de Traversay, 1994; Regecová and Kellerová, 1995; Babisch et al., 2013), Hume and Ahtamad (2013) and this study used shorter stimuli. As Rice (1996) addressed, social surveys can study long-term noise exposure but it may involve combined noises, whereas laboratory studies can only deal with short-duration noise exposures but can isolate or control the noises.

4.4.2 General discussion

There are some recommendations for future research when it comes to the investigation of psychological and physiological responses to floor impact noise. First, as discussed in the previous section, different changes in HR have been found in different studies. As most of the laboratory experiments have used short noise stimuli (< 30 seconds), further investigation using longer stimuli would be helpful for understanding long-term changes in physiological responses. Second, individual noise sensitivity has long been known as a stable personality trait which has a significant influence on the prevalence of noise annoyance (Job, 1988; Öhrström et al., 1988; Ellermeier et al., 2001; Kang, 2006). In particular, Öhrström et al. (1988) stated that noise annoyance is affected not just by general neurophysiological sensitivity but also self-reported noise sensitivity. Future studies could focus on potential physiological indices that can represent individual noise sensitivity ratings. Third, the loudspeakers could be located above the participants to simulate the noise from the upper floor and a subwoofer could be used to reproduce low-frequency sounds below 50 Hz.

4.5 Summary

This study investigated participants' psychological responses (noticeability and annoyance) and physiological responses (HR, EDA, and RR) to floor impact noise produced by both real and standard sources. The findings showed that noticeability increased with as the noise level increased and the standard impact noise led to higher noticeability than the real impact noise. Noise annoyance ratings also increased as the noise level increased. The annoyance ratings of the standard impact noise were also greater than the real impact noise. The deceleration in HR, increases in EDA and RR were found during the noise exposure, implying that noise exposure influenced the arousal status of the participants. The physiological responses were not affected by the type of noise source, whereas the noise level affected EDA and RR. In addition, noticeability and annoyance correlated with EDA and RR when the standard impact noise was presented. Annoyance also correlated with EDA when the real impact noise was presented. The correlations were statistically significant but not very strong. Future research is required to further understand the effects of long-term noise exposure and participants' personal factors such as noise sensitivity. Table 4-6 summarises the major findings of this study with the research questions of the study.

Table 4-6. The research questions and the findings of this study.

Research questions	Findings
▪ How do people respond to floor impact noise psychologically and physiologically?	▪ Psychological responses - Noticeability and annoyance (increase) ▪ Physiological responses - Heart rate (deceleration) - Electrodermal activity (increase) - Respiration rate (acceleration) ⇨ Potential adverse health effects
▪ What factors have impacts on the responses?	▪ Noise level had impacts on noticeability and annoyance. ▪ Noise level had no impact found on heart rate but had impacts on electrodermal activity and respiration rate. ▪ The standard impact noise evoked higher noticeability and annoyance than the real impact noise did. ▪ The physiological responses were not significantly affected by the difference between the real and standard impact noises.

5 Effects of noise sensitivity on psychological and physiological responses to floor impact noise: A laboratory study*

5.1 Introduction

In the previous study (Chapter 4), it was discussed that further investigation into the effects of longer noise stimuli and noise sensitivity is needed. This study assessed the effect of noise sensitivity on psychological and physiological responses to floor impact noise stimuli which lasted longer than those in the previous study. Noises generated by a standard impact source (impact ball) and two real impact sources (an adult's walking and a child's running) were used as the floor impact noise stimuli and one road traffic noise stimulus was used in order to compare the responses to indoor and outdoor noises. A total of 34 participants took part in the study and they were grouped into low and high noise-sensitivity groups. The noise stimuli were presented for 5 minutes each. Annoyance, heart rate, electrodermal activity, and respiratory rate were measured throughout the experiment. The study

---

[*] This chapter has been partly published in a peer-reviewed journal and a conference proceeding. The papers can be found in Appendix 7.

was conducted based on the following research questions and objectives as shown in Table 5-1.

Table 5-1. The research questions and objectives of the present laboratory study.

Research questions	Objectives
▪ How do people respond to floor impact noise psychologically and physiologically?	▪ To investigate annoyance response to floor impact noise. ▪ To investigate physiological responses to floor impact noise: heart rate, electrodermal activity, and respiration rate.
▪ What factors have impacts on the responses?	▪ To investigate the impacts of the following factors on the responses: - Noise level - Type of noise source (real and standard impact noises, and road traffic noise) - Duration of the noise exposure - Self-reported noise sensitivity - Attitude towards neighbours

5.2 Methods

5.2.1 Participants

A screening survey was first conducted online with potential participants. The survey link was emailed to those who showed their interest in participating in the experiment. They were asked to answer several questions about their demographic characteristics, previous experience of being exposed to floor impact noise, and self-reported noise sensitivity. Noise sensitivity was evaluated using the 21 questions developed by Weinstein (1978) using 6-point scales (1 = *'Strongly agree'* to 6 = *'Strongly disagree'*). Attitude towards their upstairs neighbours was assessed using six questions listed in Table 5-2. The attitude questions were asked with 5-point scale (1 = *'Strongly agree'* to 5 = *'Strongly disagree'*).

Table 5-2. Question items to measure attitudes to neighbours.

Korean version: original

“윗집 이웃에 대해 어떻게 느끼고 계신가요?”

1 윗집 이웃은 좋은 사람들이다.
2 윗집 사람들이 내 이웃이라는 사실에 만족한다.
3 윗집 이웃과 나는 서로 공감할 수 있는 부분이 많다.
4 나는 윗집 이웃의 상황을 잘 알고 있고, 이해하고 있다.
5 나는 윗집 이웃을 보면 반갑게 인사한다.
6 윗집 이웃은 우리를 위해 최대한 소음을 내지 않으려고 노력한다.

English version: translated

“How do you feel about your upstairs neighbours?”

1 They are good people.
2 I am happy to be their neighbour.
3 We understand each other in many things.
4 I know and understand their situation very well.
5 We greet each other with a friendly hello.
6 They try not to make as much noise as possible for us.

This study aimed to recruit at least 26 participants in order to obtain 80 % power with $a = .05$; it was estimated based on the data of the previous study in Chapter 4 (Faul et al., 2007; Faul et al., 2009). A total of 34 participants were chosen based on their responses to the screening survey. None of the participants had hearing disabilities. From the whole respondents to the screening survey, those who had experienced the floor impact noise exposure were first included. Then, those with low or high noise sensitivity were invited to participate in the study. The low noise-sensitivity group’s median noise sensitivity score was 61 and that of the high noise-sensitivity group was 99. As listed in Table 5-3, the same number of participants were recruited for both noise-sensitivity groups. They included 13 males and 21 females aged between 30 and 48 ($M = 38.8$, $SD = 5.3$). Half of them were in their 30s and the other half in their 40s. Thirteen participants were either not married or married but had no children and the others reported that they had one or more children. It was found that 14 participants had positive attitudes to their upstairs neighbours, whereas other 20 participants had negative attitudes to their upstairs neighbours. Attitude scores were not significantly different between the low and high noise-sensitivity groups. Length of residency in their current houses was three years on average. Eighteen participants had lived in their current residence for less than three years and the rest had lived in their residences for more than three years. Besides, 12 participants had mad noise complaints (e.g. making complaints directly to their neighbours, through management offices, through police, etc.) regarding the noise from their upstairs neighbours.

Table 5-3. Information of the participants (*N* = 34).

		Number	%
Gender	Male	13	38.2
	Female	21	61.8
Age	30s	17	50.0
	40s	17	50.0
Noise sensitivity	Low	17	50.0
	High	17	50.0
Child(ren) at home	Yes	21	61.8
	No	13	38.2
Attitude to upstairs neighbours	Positive	14	41.2
	Negative	20	58.8
Length of residency	Less than 3 years	18	52.9
	More than 3 years	16	47.1
Experience of making noise complaints	Yes	12	35.3
	No	22	64.7

5.2.2 Noise stimuli

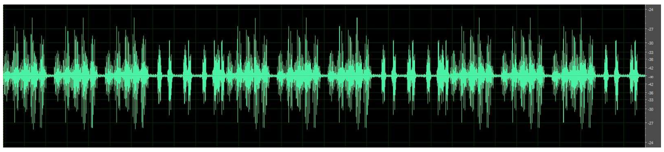
In this study, both floor impact noise and road traffic noise were used as noise stimuli. Floor impact noise was generated by real human footsteps ('Real') and a standard impact source, impact ball ('Standard'). The floor impact noise was recorded in the test building where the previous study conducted the recordings (Chapter 4). The test building was designed to simulate the living rooms of residential buildings in South Korea. Background noise level inside the test building was approximately 25 dBA. The floor layer of the building consisted of a 210 mm thick concrete slab, a 30 mm thick resilient material, a 40 mm thick lightweight concrete, and 40 mm thick mortar. All the rooms were furnished and wooden flooring was installed as a finishing material. The shape of the room was rectangular (4.5 m × 3.5 m) and the volume was around 38 m^3. An adult walking barefoot and a child running barefoot were chosen as the real noise stimuli sources as these noises were the dominant noises in multi-family residential buildings in the previous study (Chapter 3). An impact ball noise (ISO 10140-5) was recorded as the standard impact noise stimuli. All the floor impact noises were generated in the source room upstairs and the noises were recorded binaurally using a head and torso simulator (Brüel & Kjær Type 4128C) positioned on a sofa in the receiving room downstairs. Road traffic noise ('Traffic') was recorded in the suburb of Liverpool, UK. Appendix 3 displays a map of the location where the recording was carried out. A microphone (Behringer ECM8000) connected to a digital recorder (ZOOM H4n) was positioned 2 m away from the road and 1.5 m above the ground. The width of the road was 11 m (≒ 35 feet) with two lanes and the average vehicle speed was below 60 km per hour (≒ 37 mph). The traffic flow was fluctuating due to a roundabout located around 160 m (≒ 0.1 miles) away. Using the recordings, all the noise stimuli were edited to last for 5 minutes. For the floor impact noise, only signals in the right channel were extracted from the binaural recordings in order to avoid any possible effects of spatial characteristics on perception (Jeon et al., 2009a). Each stimulus was reproduced to be played at each noise level, and saved as a separate audio file (.wav). All sound reproduction procedures were carried out using audio editing software (Adobe Audition). L_{AFmax} of the floor impact noise stimuli were fixed at 40, 50, and 60 dBA. The road traffic noise was set to be played at 40 and 60 dBA (L_{Aeq}). Temporal features of the noise stimuli are listed in Table 5-4 in terms of L_{Aeq}, L_{AFmax}, and L_{AE}.

Table 5-4. L_{AFmax}, $L_{\mathrm{Aeq},}$ and L_{AE} of the noise stimuli.

Stimuli source	Label	L_{AFmax} [dBA]	L_{Aeq} [dBA]	L_{AE} [dBA]
Real	R40	40.0	30.1	54.9
	R50	50.0	38.9	63.7
	R60	60.0	48.9	73.7
Standard	S40	40.0	29.3	54.1
	S50	50.0	37.8	62.6
	S60	60.0	47.6	72.4
Traffic	T40	48.8	40.0	64.8
	T60	68.8	60.0	84.8

The noise of the impact ball was recorded at regular intervals between the impacts; it was edited to replicate the footstep noise as Figure 5-1(b) shows. For the road traffic noise, spectral filtering was applied to simulate the outdoor-to-indoor noise attenuation using the condition of a closed window (Vos, 2003). Of different simulated closed windows proposed by Vos (2003), the attenuation with a median degree of isolation was adopted in this study as in Lee et al. (2010). Figure 5-2(a) illustrates the frequency characteristics of the two floor impact noises at 60 dBA (L_{AFmax}) and Figure 5-2(b) describes those of the road traffic noise at 60 dBA ($L_{\mathrm{Aeq,5\text{-}minute}}$). Compared with the road traffic noise, the two floor impact noises had their dominant sound pressure levels at low frequencies below 125 Hz.

(a) R60: Real at 60 dBA (L_{AFmax})



(b) S60: Standard at 60 dBA (L_{AFmax})

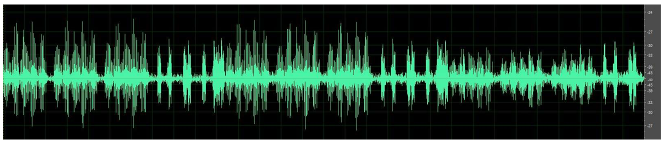


Figure 5-1. Waveforms of the (a) real and (b) standard impact noise stimuli.

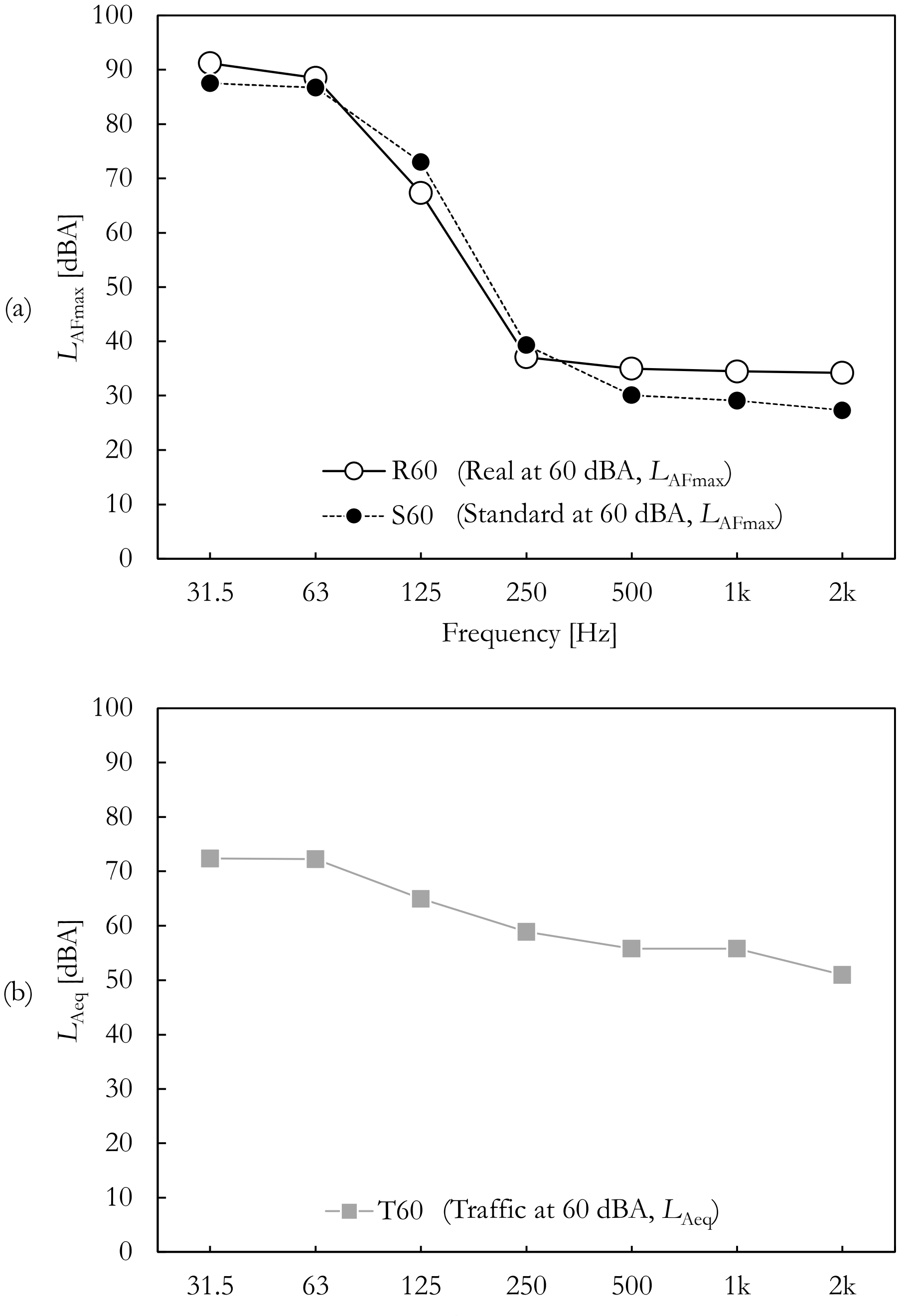


Figure 5-2. Frequency characteristics of the noise stimuli: (a) the floor impact noise stimuli and (b) the road traffic noise stimuli.

5.2.3 Experimental design

Eight stimuli were presented to each participant with randomised order of noise levels and sources to minimise the order effects (Jennings and Gianaros, 2007). Time for rating noise annoyance was given after each stimulus presentation. The sounds above 63 Hz were reproduced using a loudspeaker (Genelec 8050A) and the low-frequency sounds below 63 Hz were presented using a subwoofer (Velodyne MicroVee). A low-pass filter with a cut-off frequency of 63 Hz in the octave band was applied to the noises reproduced by the subwoofer. The loudspeaker was positioned above the participant and the subwoofer was placed on the floor in front of the participant in 2 m distance. An additional loudspeaker (Genelec 8050A) was used for playing ambient noise at 31 dBA ($L_{\mathrm{Aeq,1\text{-}hour}}$) and it was positioned in front of the participant in 2 m distance.

5.2.4 Response measurements

After each noise exposure for five minutes, the participant was asked to rate their annoyance using an 11-point scale (0 = '*Not at all*' to 10 = '*Extremely*') as recommended in Fields et al. (2001) and the ISO/TS 15666. Three physiological responses were measured for the entire duration of each session: heart rate (HR), electrodermal activity (EDA), and respiration rate (RR). All the physiological responses were measured using the MP 150 WSW digital acquisition system (BIOPAC Systems), recorded and analysed via a data acquisition/analysis software (AcqKnowledge 4.4, BIOPAC Systems). Two wireless amplifiers were placed outside the room where the participant was located (Appendix 3). The amplifiers received all the physiological signals via Bluetooth transmitting mode. HR was derived from the raw electrocardiograph data which were measured using three electrodes attached to the participant's right wrist and both ankles. EDA was measured using two electrodes attached to the participant's index and middle fingers of the right hand. RR was computed from the raw respiration data which were measured with a respiration transducer belt worn around the chest. The respiration transducer belt records respiration data by measuring the changes in thoracic circumference that occur when the participant breathes.

5.2.5 Procedure

Only those who provided their consent participated in the study. The participants took part in the experiment individually. Each participant was asked to avoid staying up late and not to drink any alcohol or caffeinated drinks before the experiment. The participant information sheet and a written consent form were provided to the participant upon arrival. Before obtaining the consent, the author explained the purpose of the study and answered the participant’s questions. The participant was assured of complete anonymity. Once all the electrodes were attached to the participant’s body, the participant was then helped to be seated comfortably on a chair. A training session was first carried out in order to help the participant to get used to the environment and the measurement, as well as to check if all the measurement systems were working properly. The participant was asked to imagine that they were resting in their own home. The room temperature and humidity were kept constant throughout the experiment to avoid any effects on the physiological responses (Boucsein, 2012). Each participant received KRW 30,000 (approximately GBP 20) gift card for the participation. The laboratory experiment was conducted in an audiometric booth with a low background noise level (below 25 dBA) in the Fire Insurers Laboratories of Korea. The floor area was about 35.7 m^2 (4.8 m × 7.43 m) and it simulated the area of a living room in most common apartments of South Korea. The shape of the room was rectangular with a volume of 93.8 m^3 (4.8 m × 7.43 m × 2.63 m).

5.2.6 Data analysis

Any erroneous data in the physiological measurements were discarded before the analysis (Schneider et al., 2003; Jennings and Gianaros, 2007). Percentage changes [%] of the physiological responses were calculated derived from the changes from the baseline to noise exposure (Kaiser, 1989).

Six time-blocks of physiological data were analysed in order to study whether the physiological responses varied over the noise exposure for five minutes. Figure 5-3 displays a simple illustration of how the physiological responses were computed for 30 seconds, 1 minute, 2 minutes, 3 minutes, 4 minutes, and 5 minutes from the beginning of the noise exposure.

Statistical analyses were performed using SPSS for Windows (version 22). Bivariate (Pearson) correlations were assessed between two variables. The repeated measures ANOVA were tested in order to examine the effects of noise level, type of sources, and duration of the noise exposure on the responses. Wilcoxon signed-rank tests were carried out to assess the differences in the responses between the real and standard impact sources. Group differences were examined using the Mann-Whitney U tests and independent samples *t*-tests. *p* values of less than 5 % ($p < 0.05$) were considered as statistically significant.

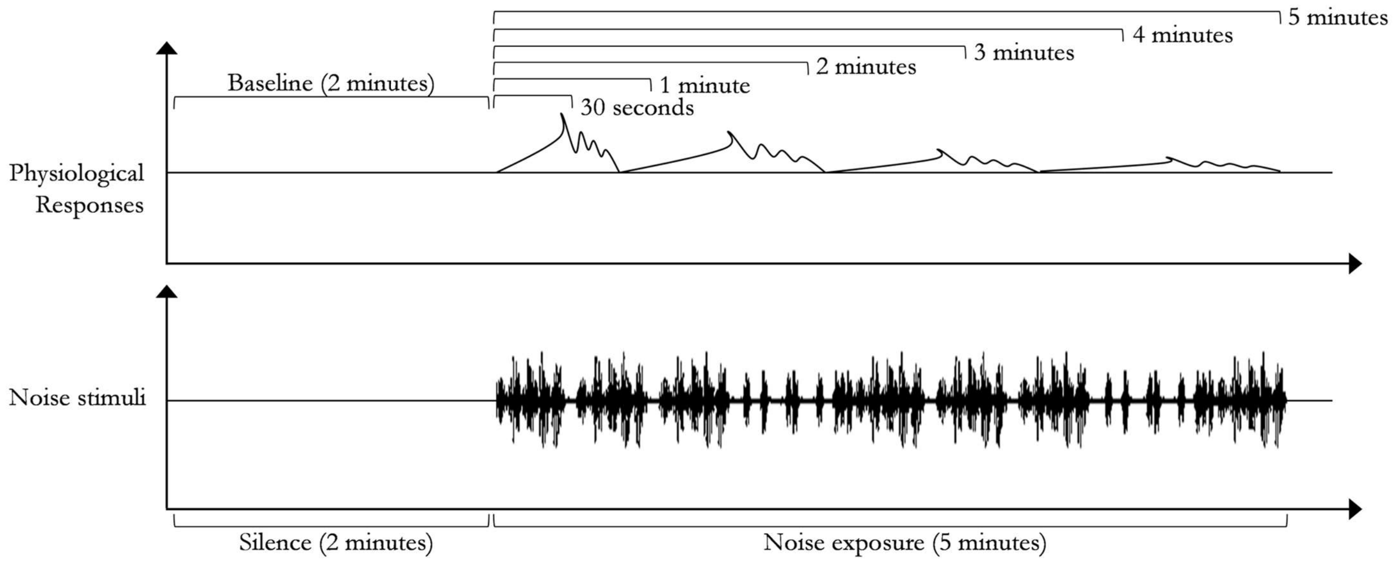


Figure 5-3. An illustration showing how the physiological responses for different durations were calculated.

5.3 Results

5.3.1 Annoyance

Figure 5-4 shows annoyance ratings for different noise stimuli as functions of L_{AFmax}. It was found that noise annoyance ratings of all noise sources increased as the noise level increased. Correlation coefficients between annoyance ratings and noise level were 0.75 and 0.78 for the real and standard impact noises, respectively ($p < 0.01$). The effect of the noise level on annoyance was significant [F (1, 40) = 77.20, $p < 0.01$]. It was observed that the noise source had a significant effect on annoyance [F (1, 33) = 20.18, $p < 0.01$]. Annoyance ratings for the real impact noise were significantly higher than the ratings for the standard impact noise at 40 and 60 dBA. Annoyance rating for T40 was close to those for R50 and S50; annoyance rating for T60 was significantly higher than those for other stimuli.

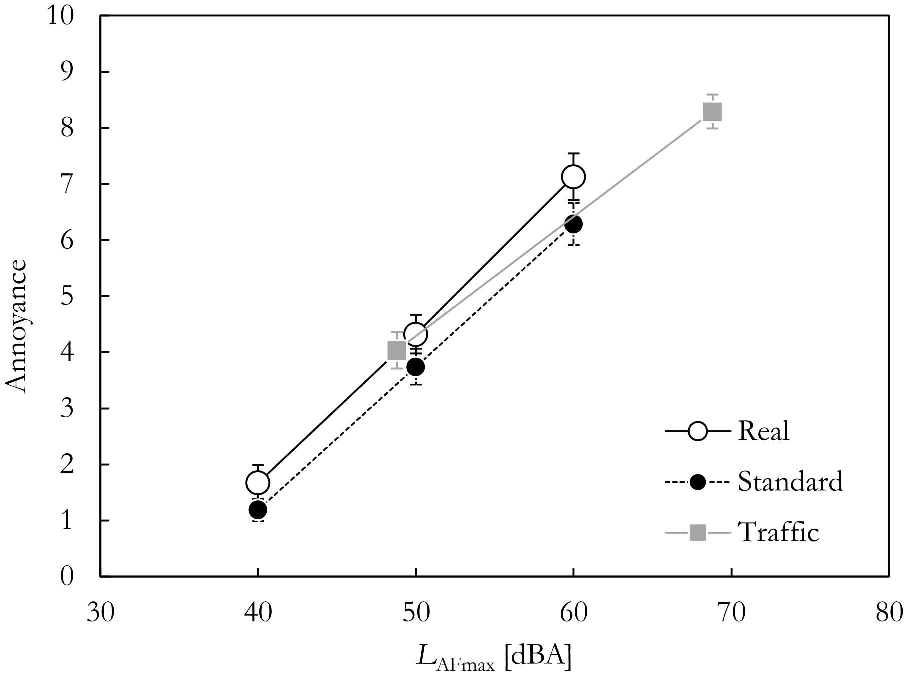
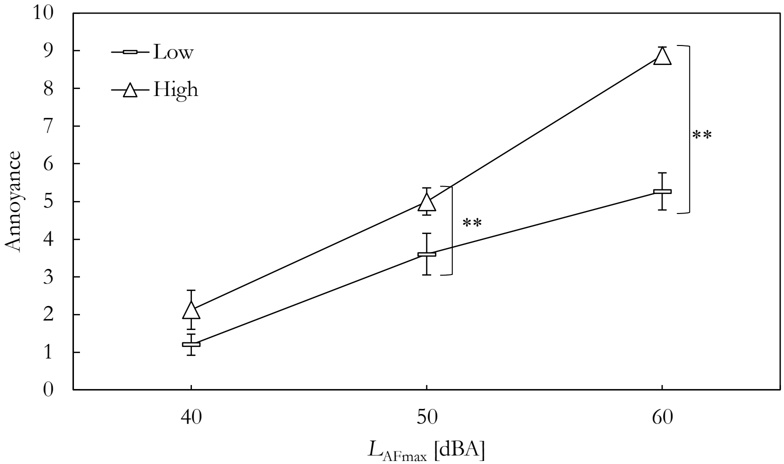


Figure 5-4. Annoyance for the noise stimuli as a function of L_{AFmax}. Error bars indicate standard errors.

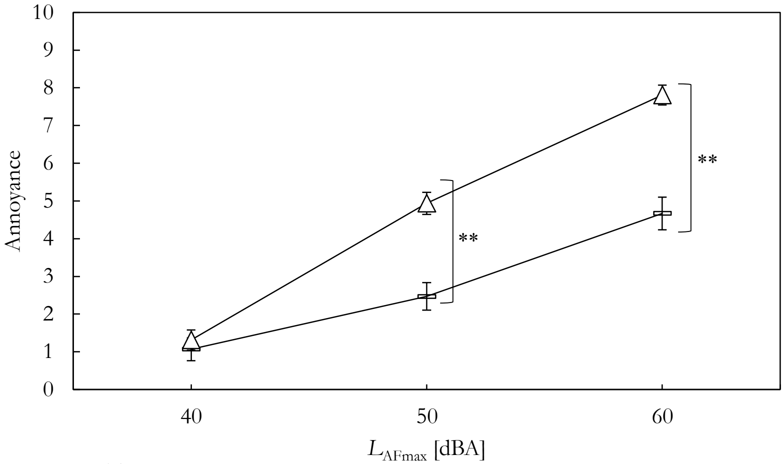
In order to investigate the effect of noise sensitivity on noise annoyance, noise annoyance ratings of the low and high noise-sensitivity groups were compared.

As described in Figure 5-5, the high noise-sensitivity group reported higher annoyance ratings than the low noise-sensitivity group when the floor impact noise stimuli were presented. The differences between the two groups increased as the noise level increased and significant differences were found at 50 and 60 dBA. A similar tendency was shown for the road traffic noise, with a significant difference between the groups at 60 dBA. For the low noise-sensitivity group, correlations between annoyance ratings and noise level were statistically significant ($r = .71$, $p < 0.01$ for the real impact noise and $r = .73$, $p < 0.01$ for the standard impact noise). Noise level had a significant impact on annoyance [F (1, 21) = 19.40, $p < 0.01$] and noise source also had a significant effect on annoyance [F (1, 16) = 11.51, $p < 0.01$]. Similarly, for the high noise-sensitivity group, the correlation between annoyance and the noise level was also significant and bigger than that of the low noise-sensitivity group ($r = .88$, $p < 0.01$ for the real impact noise and $r = .93$, $p < 0.01$ for the standard impact noise). Annoyance was significantly affected by noise level [F (1, 22) = 165.31, $p < 0.01$] and noise source [F (1, 16) = 8.34, $p < 0.05$].

(a) Real



(b) Standard



(c) Traffic

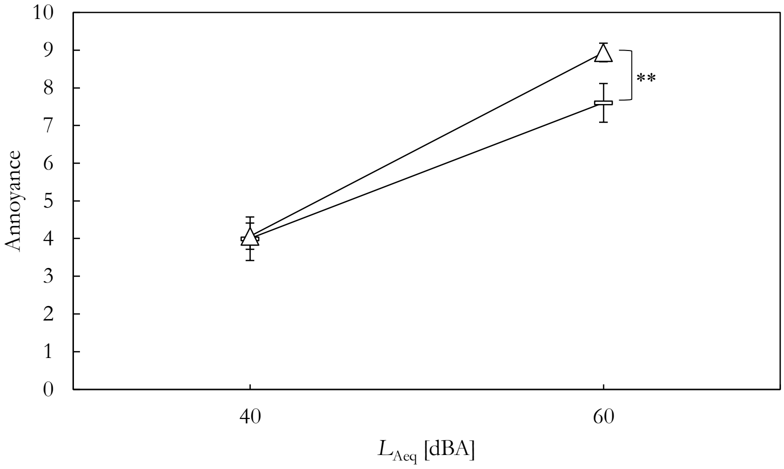


Figure 5-5. Annoyance compared between the low and high noise-sensitivity groups as a function of L_{AFmax}: (a) Real, (b) Standard, and (c) Traffic. Error bars indicate standard errors.

5.3.2 Heart rate, electrodermal activity, and respiration rate

In order to investigate how the physiological responses changed over time, mean changes of HR, EDA, and RR were calculated for different durations of noise exposure ranging from thirty seconds to five minutes. As described in Figure 5-6, mean changes in HR slightly increased for five minutes for both low and high noise-sensitivity groups. EDA and RR showed more pronounced dependencies on the duration than HR. It was shown that EDA and RR initially increased and then rapidly decreased as time passed. For instance, for the road traffic noise, the low noise-sensitivity group presented large variations in EDA from around 2 % to -5 %. Both noise-sensitivity groups showed similar tendencies over time but the changes of the high noise-sensitivity group were greater than those of the low noise-sensitivity group. As listed in Table 5-5, the mean changes of HR, EDA, and RR were significantly affected by the duration of noise exposure. RR showed a significant difference between the groups for all the noise sources. For the low noise-sensitivity group, the mean changes of RR recovered fairly quickly and even showed negative values after one minute, whereas those of the high noise-sensitivity group still remained positive after five minutes; it may imply that five minutes might not be sufficient for sensitive people to fully recover. Similar tendencies in the physiological responses were found when both floor impact noise and road traffic noise stimuli were heard. However, Figure 5-6 describes that the floor impact noise stimuli evoked a clearer difference between the low and high noise-sensitivity groups in general.

It is notable that the decreases in EDA and RR were most significant between 30 and 60 seconds. It implies that the initial changes of the physiological responses (HR deceleration, EDA increase, and RR acceleration observed for the first 30 seconds) represent the arousal status suggested in Lang et al. (1997) and the physiological responses start to recover after 30 seconds. The previous study also revealed that the 23-second long stimuli evoked responses (Chapter 4). Therefore, in this study, only the mean changes for 30 seconds were used for the detailed analyses.

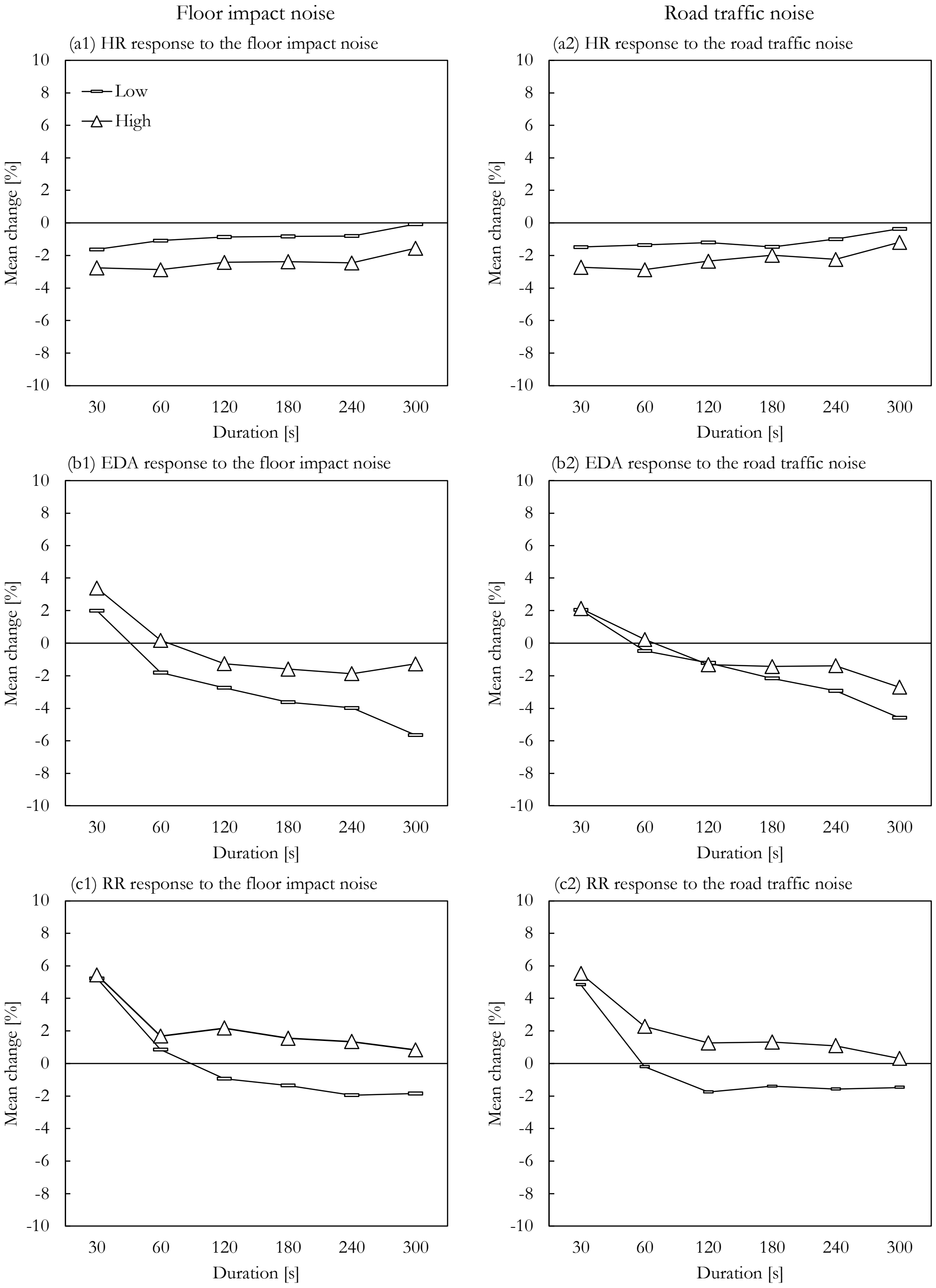


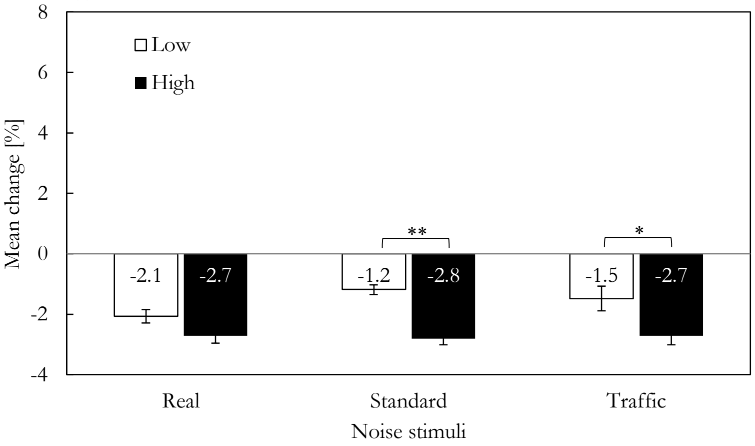
Figure 5-6. Mean percentage changes of the physiological responses over different durations of noise exposure compared between the low and high noise-sensitivity groups.

Table 5-5. Results of the repeated measures ANOVA showing the effects of the duration of noise exposure on HR, EDA, and RR (*$p < 0.01$).

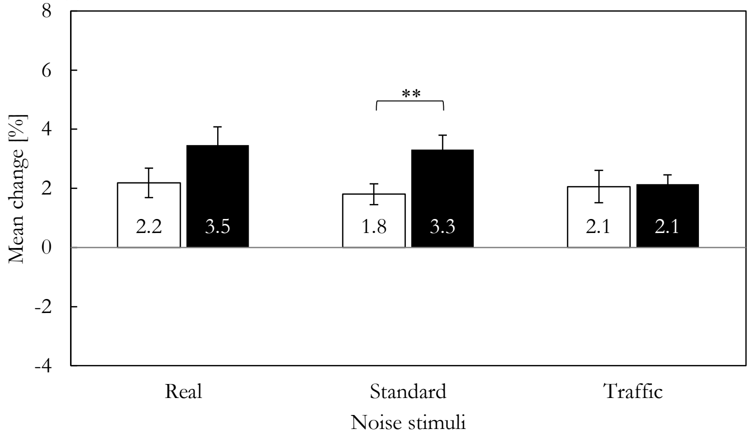
		Real		Standard		Traffic	
		df	*F*	*df*	*F*	*df*	*F*
HR	Duration	4	17.49*	4	9.43*	4	12.26*
	error	127		130		126	
EDA	Duration	2	20.74*	2	26.91*	3	22.08*
	error	61		80		99	
RR	Duration	3	26.49*	3	29.06*	3	22.46*
	error	93		99		91	

The changes in HR, EDA, and RR for 30 seconds were averaged across the noise sources and are plotted in Figure 5-7. HR decreased when the noise was played for 30 seconds, whereas EDA and RR increased. Differences between baselines and noise exposures were statistically significant for all the noise sources and all the physiological measures ($p < 0.01$). Responses of the high noise-sensitivity group were consistently greater than those of the low noise-sensitivity group across all noise sources and all the physiological measures. The two noise-sensitivity groups' HR were significantly different when the standard impact noise and road traffic noise were heard. EDA were significantly different when the standard impact noise was heard. RR were not significantly different for all noise sources. There was no significant difference between the two noise-sensitivity groups when the real impact noise was presented.

(a) HR



(b) EDA



(c) RR

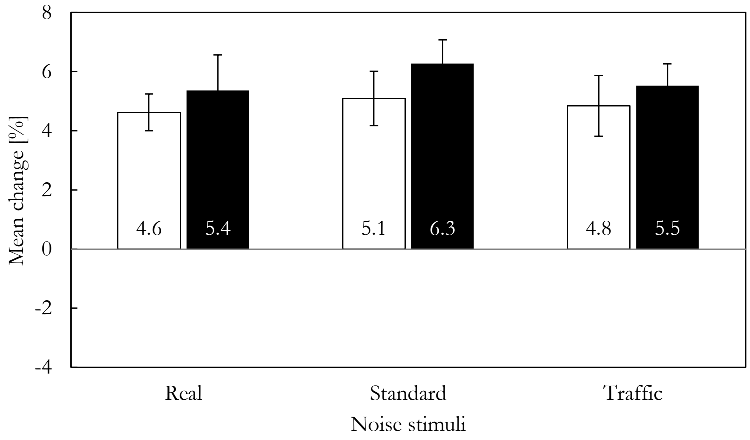


Figure 5-7. Mean percentage changes of the physiological responses for 30 seconds compared between the low and high noise-sensitivity groups (*$p < 0.05$, **$p < 0.01$). Error bars indicate standard errors.

Figures 5-8, 5-9, and 5-10 illustrate the mean changes of HR, EDA, and RR at different noise levels, respectively. The decrease in HR of the high noise-sensitivity group was greater than that of the low noise-sensitivity group at all levels and for all noise sources. However, there was no clear trend in HR changes as the noise level increased. There were some significant differences between the two noise-sensitivity groups when the stimuli were presented above 50 dBA. The high noise-sensitivity group showed greater EDA than the low noise-sensitivity group at all levels and for all noise sources but not many significant differences between the two noise-sensitivity groups were found. RR showed no clear tendency with the increasing noise level and there were significant differences between the two noise-sensitivity groups when stimuli were played at 40 dBA. Additionally, demographic characteristics (age and gender) and attitude towards neighbours did not have any impact on the responses.

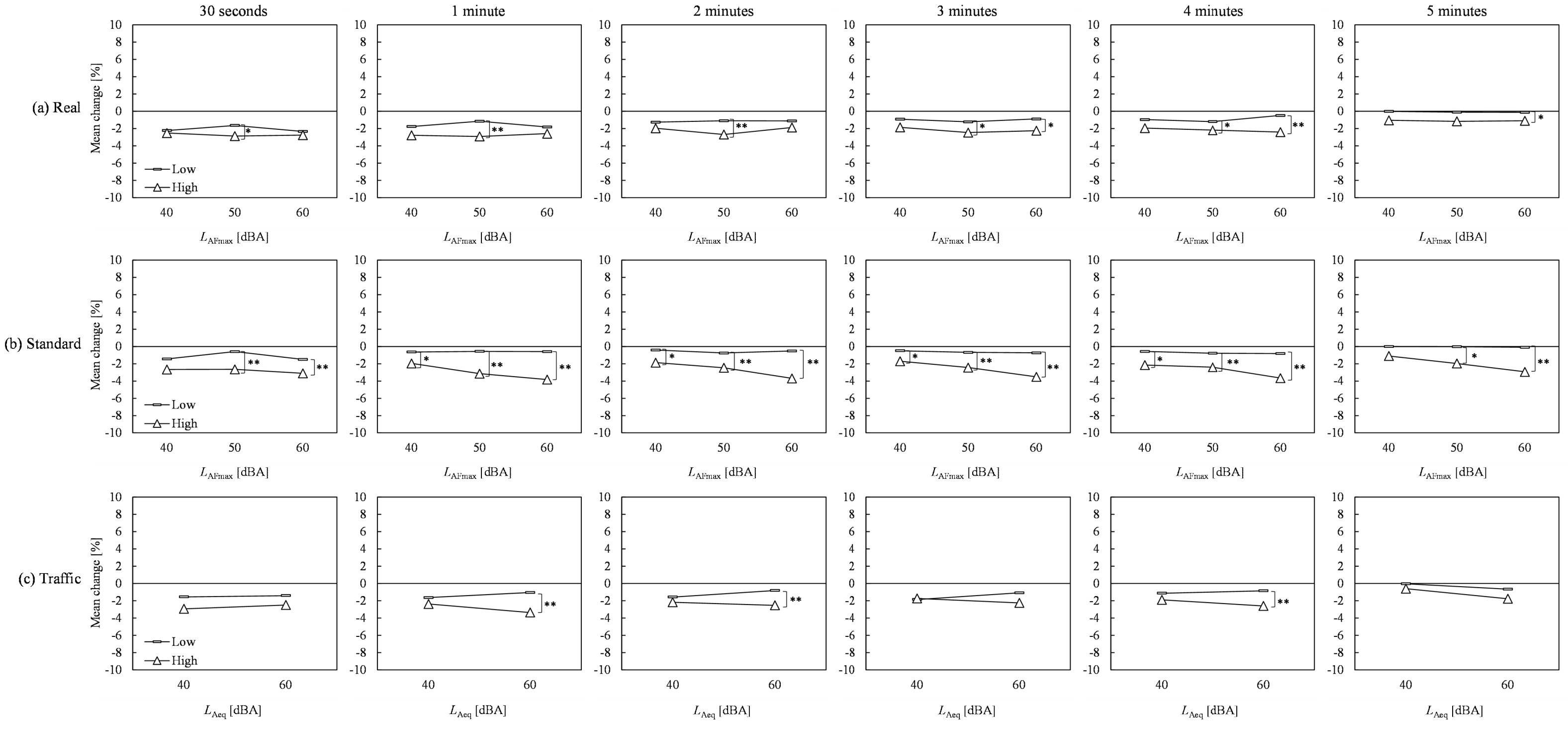


Figure 5-8. Mean percentage changes of HR compared between the low and high noise-sensitivity groups as a function of noise levels.

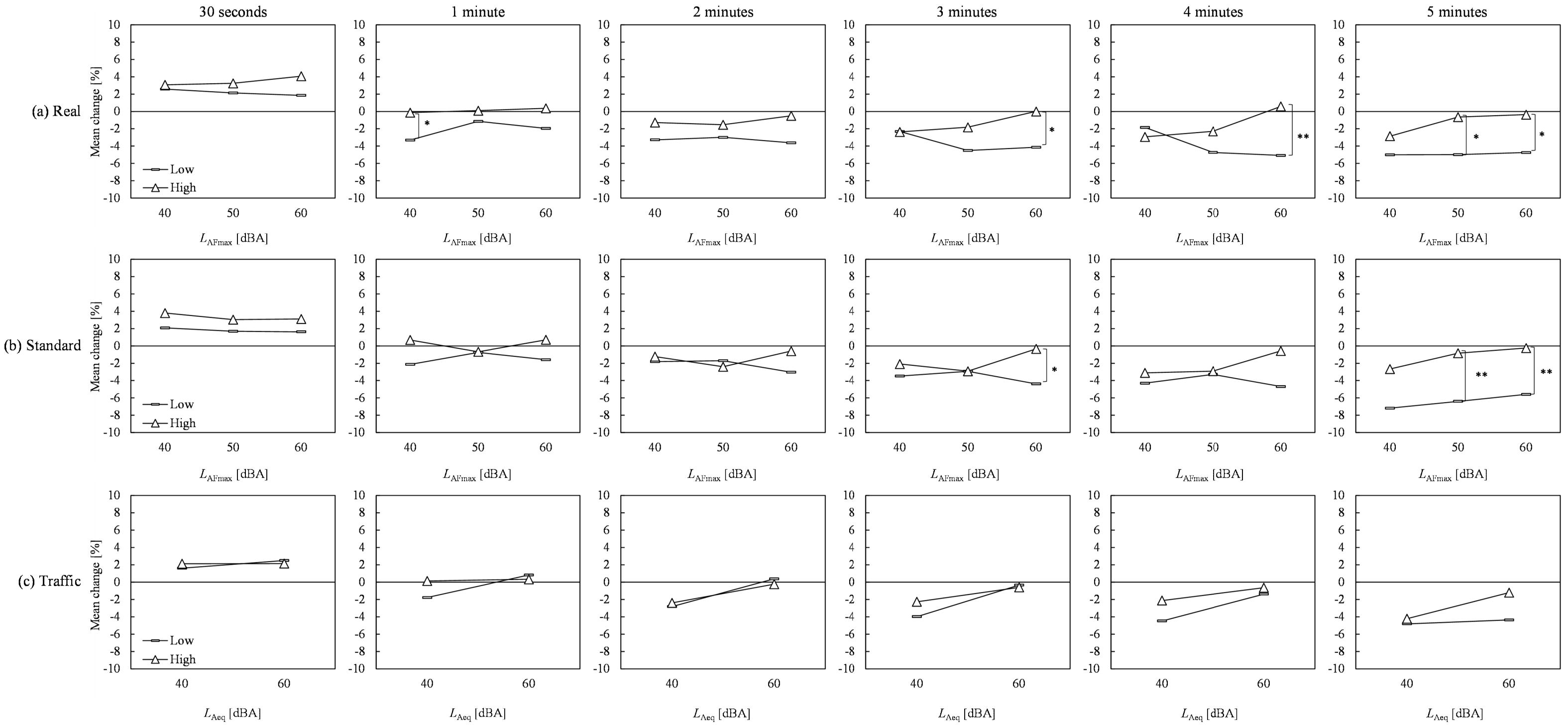


Figure 5-9. Mean percentage changes of EDA compared between the low and high noise-sensitivity groups as a function of noise levels.

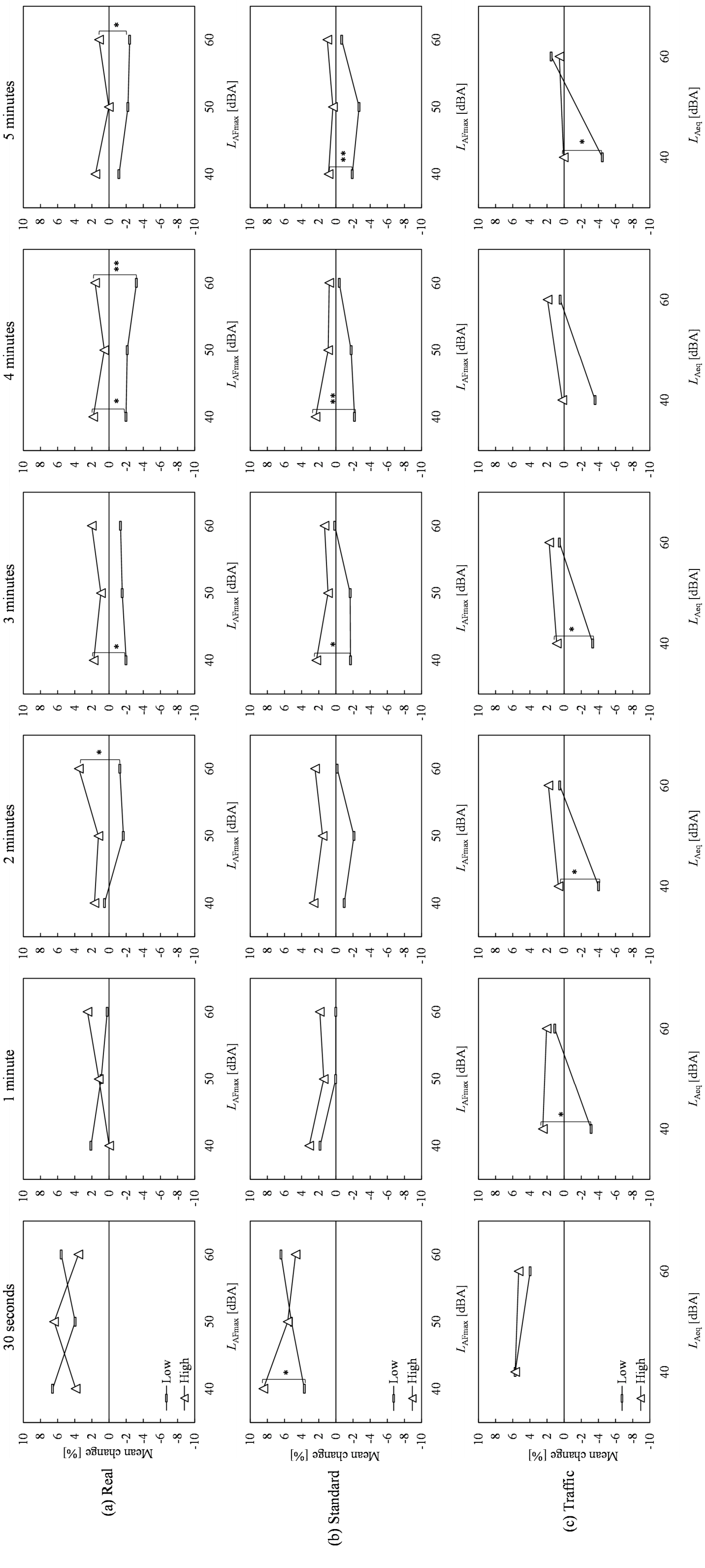


Figure 5-10. Mean percentage changes of RR compared between the low and high noise-sensitivity groups as a function of noise levels.

5.4 Discussion

5.4.1 Effects of noise sensitivity

Previous studies have mainly focused on the effects of noise sensitivity on annoyance ratings for outdoor noises such as transportation noise (Belojević et al., 1992; Stansfeld et al., 1993; van Kamp et al., 2004; Fyhri and Klæboe, 2009). This study extended the existing research by assessing indoor building noise (floor impact noise), as well as outdoor noise (road traffic noise). The findings from the study revealed that noise sensitivity significantly increased noise annoyance ratings of both indoor and outdoor noises. These results are consistent with the findings in previous research where noise sensitivity was a crucial factor affecting annoyance for the various outdoor environmental noises (Job, 1988; Öhrström et al., 1988; Belojević et al., 1992; Fields, 1993; Stansfeld et al., 1993; Miedema and Vos, 1999; van Kamp et al., 2004). Furthermore, the findings of this study confirmed that noise sensitivity influences annoyance for indoor noise by extending an earlier study on the impacts of noise sensitivity on annoyance ratings for airborne and bathroom drainage noises (Ryu and Jeon, 2011).

In the previous chapter (Chapter 4), the model that was comprised of pre-encounter, post-encounter, and circa-strike stages were introduced to discuss the physiological responses (Lang et al., 1997). To sum up the model, the post-encounter stage involves freezing responses due to the focused attention and potentiated startle and the circa-strike stage involves alarmed responses as an active defense which aims to eliminate reactions to the future stimuli. This study also showed that the physiological responses were different between the low and high noise-sensitivity groups. In particular, the physiological responses of the high noise-sensitive group were greater than those of the low noise-sensitivity group. It implied that the participants with the higher noise sensitivity had greater experiences of post-encounter and circa strike stages (Lang et al., 1997) because they paid more attention to the stimuli than those with the lower noise sensitivity.

In previous studies, noise-sensitive participants showed higher EDA and HR (Stansfeld, 1992) and cardiovascular mortality significantly increased among noise-sensitive women (Heinonen-Guzejev et al., 2007). This study also found different physiological responses between low and high noise-sensitivity groups. However, the findings of this study were partially in disagreement with Stansfeld (1992) because this study discovered the noise-sensitive participants consistently presented lower HR than participants with low noise sensitivity. This disagreement can be explained by different noise levels at which the noise stimuli were played. In this study, noise levels varied between 40 and 60 dBA, whereas Stansfeld (1992) used the stimuli at higher noise levels between 75 to 100 dBA. This implies that the noise-sensitive participants in this study paid more attention to the stimuli than low noise-sensitivity group in the post-encounter stage (Lang et al., 1997), whereas the noise-sensitive participants in Stansfeld (1992) were in the circa-strike stage due to the greater noise levels, representing bigger alarmed response than low noise-sensitivity group.

5.4.2 Effects of noise level and source

The findings of this study are in agreement with previous studies reporting that noise annoyance is significantly affected by sound pressure levels (Schultz, 1978; Miedema, 2004; Jakovljević et al., 2009). This result is also in good agreement with the previous work (Chapter 4), where the annoyance caused by floor impact noise increased with the noise level. Contrary to the noise annoyance, this study found that the physiological responses were not affected by the noise level for different noise sources. However, the previous work (Chapter 4) reported that EDA and RR changes were related to the noise level. The disagreement may be attributed to the different experimental settings of the two studies. The previous experiment employed a wider range of noise levels (from 31.5 to 63 dBA) than the current study. It was more likely to investigate the relationship between the varying noise levels and physiological responses in the previous study. In contrast, this study tested only three noise levels (40, 50, and 60 dBA) with the main concerns on assessing the effects of longer duration and noise sensitivity, so the impact of the noise level on the physiological responses could not be confirmed due to the limited data.

It has been known that different airborne sound sources also have different psychoacoustic characteristics (e.g. Neubauer and Kang, 2014). Likewise, different impact noise sources were found to evoke different psychological responses in the previous experiment (Chapter 4). In particular, annoyance was significantly higher when the standard impact noise was presented in Chapter 4 whereas the real impact noise evoked significantly higher annoyance in this study. It might be due to the difference of how the impact ball noise was presented. In the previous study (Chapter 4), the impact ball noises consisted of ten single impulsive noises played at regular intervals with significantly different waveforms from the real impact noises. On the other hand, this study edited the impact ball noise to replicate the waveform of the real impact noise of human footsteps. Given that annoyance was still different between the real and standard impact sources in this study, this result implies that human hearing and perception (i.e. subjective annoyance rating) are more sensitive than physiological responses to the differences between the impact ball and real impact noises.

5.4.3 General discussion

Several studies have reported that attitudinal factors affect noise annoyance (Job, 1988; Miedema and Vos, 1999; Kroesen et al., 2008; van Kamp et al., 2016a). However, this was not the case in this study. It can be seen that the questions used in this study to measure the attitude of the participants to their neighbours might have not been chosen in the best way. Contrary to most of the environmental noise studies in which the attitudes towards the noise sources (e.g. wind turbines and aircraft) can be measured with questions such as perceived financial benefits from the source (Miedema and Vos, 1999; Kroesen et al., 2008; Pedersen et al., 2009), it was more complicated to assess the attitudes towards the neighbours who would be the major noise source. Thus, this study asked the participants to answer six questions about how they thought about their upstairs neighbours. Given that noise annoyance is closely linked with negative emotions (Guski, 1999), future research may examine residents' emotions evoked by the neighbours and their noises. It would yield further insight into understanding attitudinal variables in the experience of neighbour noise exposure.

Confirming the findings from the previous laboratory experiment (Chapter 4), this study found HR deceleration, EDA increase, and RR acceleration at the beginning of the noise exposure. The HR deceleration and EDA increase indicated that the participants were in the post-encounter stage which accompanies with the freezing responses such as focused attention and potentiated startle (Lang et al., 1997). Moreover, the HR acceleration and the continuous increase in EDA as time went by indicated that the participants were in the circa-strike stage (Lang et al., 1997). The HR acceleration can be interpreted as the phase in which the participants experienced stronger arousal. However, the HR acceleration can also be seen as the habituation or recovery phase occurred after a certain degree of deceleration (Watson et al., 1972). Habituation is defined as a decrease in the strength of the response after repeated presentation of the same stimulus (Groves and Thompson, 1970). During the experimental sessions, the stimulus presentation lasted for five minutes. Therefore, there is a possibility that the responses evoked by the same stimulus could induce habituation or recovery. Similar tendencies were discovered in the EDA and RR changes, indicating there were strong habituations over time (Watson et al., 1972; Jackson, 1974). The EDA and RR increased by the initial stimulus exposure and then sharply decreased after 30 seconds. Most changes in the EDA and RR over time stabilised in the region between one minute and five minutes. These results clearly indicated that the participants experienced arousal at the beginning due to the noise exposure, but their responses started to show habituation after a certain period of time. Previous studies have also reported that the initial arousal responses changed and recovered over time. Brosschot and Thayer (2003) measured HR together with the emotional arousal for eight times with one-hour intervals. They found HR recovery and that the negative emotions delayed HR recovery. Further, Gerin et al. (2006) measured HR and blood pressure simultaneously with performing anger-recall tasks. They also reported that blood pressure recovered and it took longer to recover when the participants ruminated about their past events which involved anger. From the findings of Brosschot and Thayer (2003) and Gerin et al. (2006), it can be assumed that emotional responses would have substantial impacts on physiological responses. Future research would be of worth to assess emotional responses evoked by floor impact noise in order to understand human response to this noise issue more broadly.

5.5 Summary

This study investigated psychological and physiological responses (annoyance, HR, EDA, and RR) to floor impact noise and road traffic noise for the low and high noise-sensitivity groups. It was found that the annoyance ratings increased with the increasing noise level. The high noise-sensitivity group reported significantly greater annoyance ratings than the low noise-sensitivity group for all the sources. The physiological responses to noise stimuli were calculated for different durations of noise exposure from ranging 30 seconds to 5 minutes. There were HR deceleration, EDA increase, and RR acceleration for the first 30 seconds of the noise exposure. The high noise-sensitivity group showed more pronounced changes in the physiological responses than the low noise-sensitivity group. EDA and RR initially increased and then rapidly decreased after 30 seconds, indicating strong habituation over time. The differences in the physiological responses between the two noise-sensitivity groups were clearer when the floor impact noise stimuli were heard compared with the road traffic noise presentation. Noise source and noise level did not have statistical impacts on the physiological responses. Demographic factors and attitude towards neighbours did not affect the responses. Further study is needed to examine residents' emotional experience in noise exposure in order to understand the responses to this very noise issue more in-depth. Table 5-6 presents the summary of the major findings of this study with the research questions of the study.

Table 5-6. The research questions and the findings of this study.

Research questions	Findings
▪ How do people respond to floor impact noise psychologically and physiologically?	▪ Psychological responses - Annoyance (increase) ▪ Physiological responses - Heart rate (deceleration) - Electrodermal activity (increase) - Respiration rate (acceleration) ⇨ Potential adverse health effects
▪ What factors have impacts on the responses?	▪ Noise level increased annoyance but had no impact on the physiological responses. The contrast finding from the previous chapter could be due to the range of noise levels (10 different noise levels vs. 3 different noise levels). ▪ The physiological responses recovered as time went by (noise length). ▪ Greater responses were found from the participants with higher noise sensitivity. ▪ Real impact noise vs. Standard impact noise - The real impact noise evoked higher annoyance than the standard impact noise did. The contrast finding from the previous chapter could be due to the length of the stimuli (23 seconds vs. 5 minutes) or the standard impact noise was presented simulating the real footstep noise this time. - The physiological responses were not significantly affected by the difference between the real and standard impact noises. ▪ Floor impact noise vs. Road traffic noise - Clearer difference between the noise-sensitivity groups was found when the floor impact noise stimuli were heard compared with the road traffic noise stimuli exposure.

6 Emotions evoked by floor impact noise: Survey and laboratory studies[*]

6.1 Introduction

Annoyance has been known to closely link to various negative emotions. In addition, physiological parameters have been adopted to examine emotional states. Previous studies (Chapters 4 and 5) have found that the exposure to floor impact noise evokes annoyance and physiological responses. It has been discussed that the evaluation of emotional response to floor impact noise would expand the existing understanding of human response to the noise. This study investigated different emotions evoked by floor impact noise exposure by focusing on lexicons (i.e. the vocabulary of a person or language). First, Korean emotion lexicons were collected from narratives of residents living in multi-family housing buildings. The lexicons were then classified into clusters based on the data collected from two questionnaire surveys (*N* = 133 and 89). Four emotion clusters were classified which mainly covered emotions related to anger, dislike, pain, and empathy. The emotions were assessed along with annoyance in a laboratory setting. Participants (*N* = 41) were exposed to the real floor impact noise stimuli at different noise levels and asked to

---

[*] This chapter has been partly published in a peer-reviewed journal and a conference proceeding. The papers can be found in Appendix 7.

rate each of the emotion lexicons and annoyance. The study was conducted based on the following research questions and objectives as shown in Table 6-1.

Table 6-1. The research questions and objectives of the present survey and laboratory studies.

Research questions	Objectives
▪ How do people respond to floor impact noise psychologically and physiologically?	▪ To investigate psychological responses to floor impact noise: annoyance and emotions.
▪ What factors have impacts on the responses?	▪ To investigate the impacts of the following factors on the responses: - Noise level - Self-reported noise sensitivity - Attitude towards neighbours

6.2 Emotion classification: Survey studies

6.2.1 Lexicon collection

Korean emotion lexicons were collected from narratives of residents living in multi-family housing in South Korea. First, interview transcripts from a previous study (Park et al., 2016a) were used to collect emotion lexicons regarding footstep noise. The interviews were carried out with 14 residents living in multi-family housing whose ages ranged from 21 to 55. Length of residency in their houses ranged from 10 months to 15 years (Park et al., 2016a). The interviewees' expressions regarding their neighbours' footstep noise were collected from the transcripts. The expressions included 'bothered', 'painful', and 'tolerable'. The second source for the lexicon collection was online communities. As listed in Table 6-2, posts on 18 different online communities were used as the source. Nine online communities concerned general topics (e.g. food, sports, and children) so the members of these communities were not restricted to residents of multi-family housing. On the other hand, the other nine communities concerned topics specifically related to the life in multi-family housing so the use of them was limited to residents living in multi-family housing.

Table 6-2. Online communities from which the emotion lexicons were collected.

Community topic	No.	Launched date of the community	Number of community members[a]	Number of collected posts
General	1	2004.02.26	3,002,761	754
	2	2003.07.11	2,639,542	1,452
	3	2007.03.03	193,842	893
	4	2009.12.31	162,714	230
	5	2006.03.30	126,532	64
	6	2006.08.26	23,813	197
	7	2012.11.19	12,197	41
	8	2004.02.22	5,425	34
	9	2012.10.02	3,339	12
For residents in multi-family housing	10	2005.10.14	20,371	3,867
	11	2010.06.15	4,430	765
	12	2012.10.25	3,816	691
	13	2014.05.12	2,282	192
	14	2011.07.01	1,758	245
	15	2016.07.11	829	96
	16	2014.06.14	645	68
	17	2011.01.11	511	129
	18	2011.12.28	150	34

[a] Date of the number counting: 28/12/2017

Lexicons about footstep noise were collected by using the keywords listed in Table 6-3. The two words ‘noise’ and ‘sound’ were used as the main keywords, and seven sub-keywords (e.g. ‘floor’ and ‘neighbour’) were used to search relevant posts. Online posts containing a combination of one main keyword and at least one sub-keyword were retrieved. Posts on other types of neighbour noise (e.g. piano sounds, voice, chair scraping noise, etc.) were then filtered out. All collected lexicons were screened based on the published research on Korean emotion lexicons (Ahn et al., 1993; Hahn and Kang, 2000; Park and Min, 2005; Sohn et al., 2012). From this process, a total of 120 lexicons expressing emotions towards neighbours’ footstep noise were extracted.

Table 6-3. Keywords which were used for searching the online postings.

Category	Keywords (English)	Keywords (Korean) [pronunciation]
Main keyword	noise	소음 [so-eum]
	sound	소리 [so-ri]
Sub-keyword	floor	바닥 [ba-dak]
	between floors/inter-floor	층간 [cheung-gan]
	neighbour	이웃 [i-ut]
	upstairs	윗집 [wit-jib]
	foot, footsteps	발 [bal]
	running, jumping	뛰는 [ttwi-neun]
	walking	걷는 [geod-neun]

6.2.2 Lexicon sampling and clustering

The 120 lexicons collected from the interview transcripts and online communities were used in the surveys (Surveys I and II). The lexicons were sampled in Survey I and clustered in Survey II. Both surveys were conducted on an online survey platform (QuestionPro). The study complied with all terms of service for the website. The survey invitation was posted on public online communities. Potential respondents were then contacted by email and asked to complete the online questionnaire via an embedded link. The email invitations clearly stated the following details of the study: (1) the aim of this study is to explore emotions towards indoor noise, (2) respondents should have normal-hearing and be residents of multi-family housing, and (3) respondents need to use headphones as they will be presented with sounds in the survey. These instructions were again displayed on the first page of each survey, along with a consent form. Only those who provided their consent by clicking "I agree" on the first screen were directed to the questionnaire. Appendix 4 displays some sample pictures of the surveys.

6.2.2.1 Noise stimuli

Footsteps made by a child and an adult were played in the surveys. This noise clip was from one of the previous laboratory experiments described in Chapter 5. The original recording was 10-second long with dominant sound energies at low-frequencies below 125 Hz. The noise was continuously played while the respondents were giving their responses to the survey.

6.2.2.2 Lexicon sampling: Survey I

Survey I listed the 120 lexicons in a randomised order to minimise the order effects (Jennings and Gianaros, 2007). The respondents were asked to listen to the noise carefully and to choose lexicons that represented their emotions towards the noise stimuli as many as they wanted. The noise stimulus was played continuously until the respondents completed the questionnaire. A total of 133 respondents (53 males and 80 females) volunteered to take part in the survey. A total of sixty the most chosen lexicons were used in the subsequent survey.

6.2.2.3 Lexicon clustering: Survey II

Sixty lexicons chosen from the prior survey (Survey I) were listed to the respondents in Survey II. The lexicons were listed in a randomised order to minimise the order effects (Jennings and Gianaros, 2007). The respondents were asked to carefully listen to the noise and to rate how much each lexicon was appropriate for expressing their emotions towards the noise stimulus, using a 5-point scale (1 = *'Not at all'* and 5 = *'Extremely'*). As listed in Table 6-4, a total of 89 respondents (43 males and 46 females) took part in the survey.

Table 6-4. Information about the respondents in Survey II (*N* = 89).

		Number	%
Age group	20s	4	4.5
	30s	10	11.2
	40s	49	55.1
	50s	21	23.6
	60s or over	5	5.6
Gender	Male	43	48.3
	Female	46	51.7

The cluster analysis method was adopted to classify the lexicons based on the respondents' ratings. The hierarchical clustering analysis was performed using SPSS for Windows (version 22). This analysis method groups similar objects into clusters by automatically computes a distance matrix. It continues merging the two most similar clusters until all the clusters are merged together. Earlier, Shaver et al. (1987) also presented the structure of emotion by presenting the hierarchical structure of emotion concepts and by specifying prototypes of the emotion categories. Based on the results, the 60 lexicons were classified into four clusters (E1, E2, E3, and E4). Emotion lexicons in E1 were mainly related to 'ANGER' (e.g. angry, vengeful), those in E2 mostly expressed 'DISLIKE' (e.g. unpleasant, bothered), those in E3 mainly expressed 'PAIN' (e.g. painful, distressing), and emotion lexicons expressing 'EMPATHY' were grouped in E4 (e.g. bearable, indifferent). As presented in Table 6-5, E1 had the most lexicons, with 21 lexicons. This may imply that the exposure to footstep noise predominantly led to emotions related to anger. As listed in Table 6-6, the top 20 lexicons were chosen based on the mean scores and they were used in the subsequent laboratory study. There were five, six, four, and five lexicons in E1, E2, E3, and E4, respectively.

Table 6-5. Sixty lexicons grouped in four clusters.

Emotion cluster	Number of lexicons	Emotion Prototype	Sample lexicons
E1	21	ANGER	get angry, get enraged, detestable, resent, fury, vengeful
E2	10	DISLIKE	awkward, bothered, irritated, unpleasant, unwelcome
E3	16	PAIN	my head is throbbing, feeling sick, painful, suffering, tired
E4	13	EMPATHY	bearable, just being patient, no reason to get irritated, tolerable

Table 6-6. Twenty lexicons used in the laboratory study.

Emotion cluster	*Mdn*	*M*	*SD*	Lexicon	Lexicon (Korean)
E1	4	3.4	1.3	unhappy	불만스럽다
	3	3.2	1.3	detestable	괘씸하다
	4	3.2	1.3	can't understand	이해가 안된다
	3	3.0	1.4	get enraged	열 받는다
	3	2.9	1.3	ridiculous	기가 막힌다
E2	4	3.7	1.2	bothered	신경쓰인다
	4	3.6	1.3	unwelcome	달갑지 않다
	4	3.5	1.3	dislike	싫다
	4	3.4	1.3	get on my nerves	예민해진다
	4	3.4	1.3	awkward	거북하다
	3	3.3	1.3	vexed	신경질난다
E3	3	3.3	1.4	suffering	괴롭다
	4	3.2	1.3	tired	피곤하다
	4	3.2	1.3	my head is throbbing	머리가 지끈거린다
	3	3.0	1.4	painful	고통스럽다
E4	3	2.9	1.3	bearable	견딜 만하다
	3	2.9	1.2	just being patient	그냥 참는다
	3	2.9	1.3	tolerable	참을 만하다
	3	2.8	1.4	no reason for discomfort	불편한 정도는 아니다
	2	2.8	1.4	think of it as usual	그러려니 한다

6.3 Emotion evaluation: A laboratory study

6.3.1 Methods

6.3.1.1 Participants

This study aimed to recruit at least 35 participants in order to obtain 80 % power with $a = .05$; it was estimated based on the data of the previous laboratory studies in Chapters 4 and 5 (Faul et al., 2007; Faul et al., 2009). A total of 41 Korean participants (22 males and 19 females) took part in the study. None of the participants had hearing disabilities. Before the experiment, each participant was asked to answer several questions about their demographic information, self-reported noise sensitivity, and attitude towards their upstairs neighbours. Noise sensitivity was evaluated using 21 questions (Weinstein, 1978). Attitude towards neighbours was measured using six questions used in the previous study (Chapter 5). As listed in Table 6-7, the majority of the participants were in their 30s and 40s. Twenty of them had one or more children. More than half of them reported that they had lived in their current dwelling for less than five years. In order to observe a clear difference between the low and high noise-sensitivity groups, participants with moderate noise sensitivity levels were excluded from the noise-sensitivity grouping. First, participants' noise sensitivity scores were divided into five groups using 20th, 40th, 60th, and 80th percentiles from the mean score distributions as cut-off points. Second, the middle range between the 40th and 60th percentiles was excluded. Thus, the low and high noise-sensitivity groups included individuals with scores lower than the 40th percentile and scores higher than the 60th percentile, respectively. The mean noise sensitivity score of the low group was 79.6 ($SD = 6.3$), and that of the high group was 102.1 ($SD = 6.4$). The low and high noise-sensitivity groups had 15 and 16 participants, respectively. Similarly, positive and negative attitude groups were also divided by excluding the middle range between the 40th and 60th percentiles. Those whose attitude scores were lower than 16 were included in the negative attitude group and those who reported attitude scores higher than

18 were included in the positive attitude group. The mean attitude score of the positive group was 23.4 (*SD* = 3.6), and that of the negative group was 13.6 (*SD* = 1.6). The positive and negative attitude groups contained 15 and 16 participants, respectively.

Table 6-7. Information about the participants of the laboratory study (*N* = 41).

		Number	%
Age group	20s	5	12.2
	30s	13	31.7
	40s	20	48.8
	50s	3	7.3
Gender	Male	22	53.7
	Female	19	46.3
Child(ren) at home	Yes	20	48.8
	No	21	51.2
Length of residency [year]	< 1	7	17.1
	1 ~ 3	12	29.3
	3 ~ 5	13	31.7
	5 ~ 10	1	2.4
	10 ~ 15	8	19.8

6.3.1.2 Noise stimuli

The same noise stimulus (footstep noise) used in the online surveys (Surveys I and II) was used in the laboratory experiment. The noise levels of the stimulus were edited in terms of L_{AFmax}, to cover a range from 30 to 60 dBA with 5 dB intervals; thus, seven noise stimuli were created. The duration of the stimuli was set to 80 seconds. The 10-second long noise clips were edited to be repeated for 80 seconds.

6.3.1.3 Experimental design

The sounds above 63 Hz were reproduced using a loudspeaker (Genelec 8050A) and the low-frequency sounds below 63 Hz were presented using a subwoofer (Velodyne MicroVee). A low-pass filter with a cut-off frequency of 63 Hz in the octave band was applied to the noises reproduced by the subwoofer. The loudspeaker was placed in front of the participant in 2 m distance, mounted at 1.2 m above the floor. The subwoofer was placed on the floor in front of the participant in 2 m distance. An additional loudspeaker (Genelec 8050A) was used for playing ambient noise at 31 dBA ($L_{\text{Aeq,1-hour}}$) and it was positioned in front of the participant in 2 m distance.

6.3.1.4 Response measurements

The participants were asked to rate 20 emotion lexicons on 7-point scales (0 = '*Not at all*' and 6 = '*Extremely*') according to the following instruction: 'Please rate how much each lexicon is appropriate for expressing your emotions perceived by the noise you are currently hearing'. Participants were also asked to rate the noise annoyance. Participants were provided with the instruction 'Please rate noise annoyance perceived by the noise you are currently hearing'. Participants used a 7-point scale (0 = '*Not at all*' and 6 = '*Extremely*') to indicate their level of annoyance. The ratings of emotions and noise annoyance were then translated into a scale from 0 to 100 for assessments of the percentage of high emotion rating (%HE) and percentage of highly annoyed (%HA). Both measures were defined as the percentages of emotion and annoyance responses which exceeded a certain cut-off point. Based on the earlier suggestion made by Schultz (1978) who used a cut-off of 72 in his synthesis to define %HA, the same cut-off point was chosen in this study for both %HE and %HA.

6.3.1.5 Procedure

Only those who provided their consent participated in the study. The participants took part in the experiment individually. The participant information sheet and a written consent form were provided to the participant upon arrival. Before obtaining the consent, the author explained the purpose of the study and answered the participants' questions. The participant was assured of complete anonymity. Each participant was guided to sit on a sofa in the middle of the room in a comfortable position and responded to the questionnaires on emotion and annoyance ratings while the noise stimuli were played for 80 seconds each. All the stimuli and lexicons listed on the questionnaires were presented in a randomised order to minimise the order effects (Jennings and Gianaros, 2007). A training session was first carried out in order to help the participant to get used to the environment and the measurement. Each participant received KRW 10,000 (approximately GBP 7) gift card for the participation. The laboratory experiment was conducted in an audiometric booth with a low background noise level (below 25 dBA) in the Fire Insurers Laboratories of Korea. The floor area was about 35.7 m^2 (4.8 m × 7.43 m) and it simulated the area of a living room in most common apartments of South Korea. The shape of the room was rectangular with a volume of 93.8 m^3 (4.8 m × 7.43 m × 2.63 m).

6.3.1.6 Data analysis

Statistical analyses were performed using SPSS for Windows (version 22). Bivariate (Pearson) correlations were assessed between two variables. The repeated measures ANOVA were tested in order to examine the effects of the noise level. Group differences were examined using the Mann-Whitney U tests and independent samples t-tests. p values of less than 5 % ($p < 0.05$) were considered as statistically significant.

6.3.2 Results

It was found that the noise level had significant effects on all emotion and annoyance ratings (Table 6-8). Figure 6-1 illustrates that the high noise-sensitivity group reported greater emotion ratings for E1, E2, and E3 than the low noise-sensitivity group. The differences between the two groups increased as the noise level increased. E4 showed opposite tendencies. The noise-sensitive participants gave lower E4 ratings than the less sensitive participants. The emotion ratings for the high noise-sensitivity group were significantly different from those for the low noise-sensitivity groups at all noise levels.

Table 6-8. Results of the repeated measures ANOVA showing the effects of noise level on emotion and annoyance ratings (*$p < 0.01$).

Measurement	Source	*df*	*F*
E1	Noise level	6	147.41*
	error	120	
E2	Noise level	4	115.44*
	error	73	
E3	Noise level	6	134.87*
	error	120	
E4	Noise level	3	133.01*
	error	58	
Annoyance	Noise level	6	272.56*
	error	120	

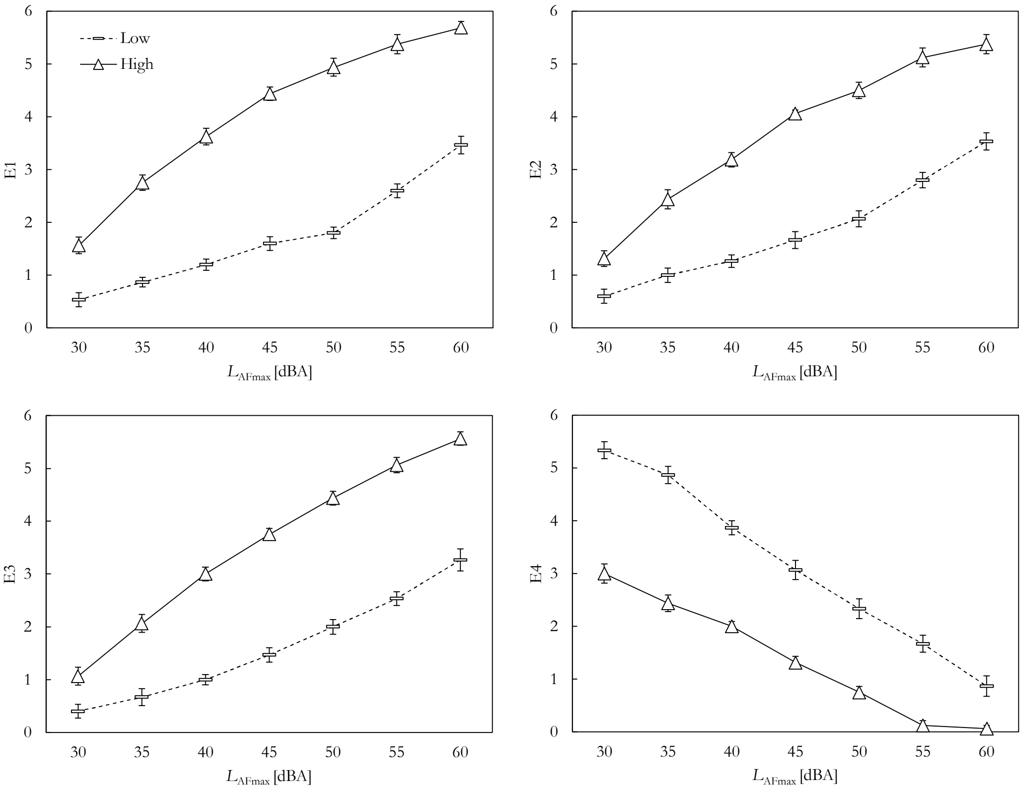


Figure 6-1. Emotions compared between the low and high noise-sensitivity groups as a function of L_{AFmax}. Error bars indicate standard errors.

Figure 6-2 shows that the negative attitude group reported greater emotion ratings for E1, E2, and E3 than the positive attitude group. The negative attitude group gave lower E4 ratings than the positive attitude group. The differences between the attitude groups were significant at some levels. For the E1 ratings, significant differences were found at 30, 35, 40, 45, and 50 dBA ($p < 0.05$). The ratings of E2 were significantly different between the attitude groups when the stimuli were presented at 45 and 60 dBA. For the E3 ratings, there were statistical significances at 30, 35, 40, 55, and 60 dBA. There was a significant difference between the attitude groups when they rated E4 at 30 dBA.

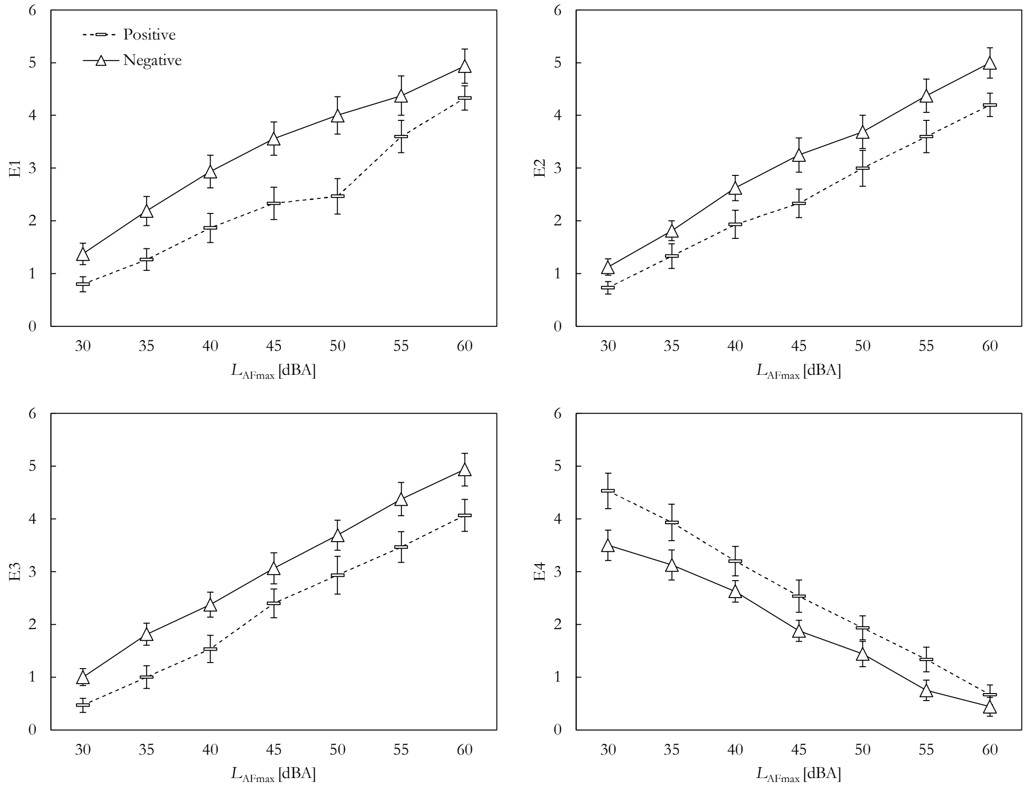


Figure 6-2. Emotions compared between the positive and negative attitude groups as a function of L_{AFmax}. Error bars indicate standard errors.

Figure 6-3 shows that the high noise-sensitivity group responded greater annoyance ratings than the low noise-sensitivity group. The annoyance ratings for the high noise-sensitivity group were significantly different from those for the low noise-sensitivity groups at all noise levels. Figure 6-4 illustrates that the negative attitude group reported greater annoyance ratings than the positive attitude group. Unlike the differences between the noise-sensitivity groups, there was no statistical significance between the attitude groups when annoyance ratings were measured.

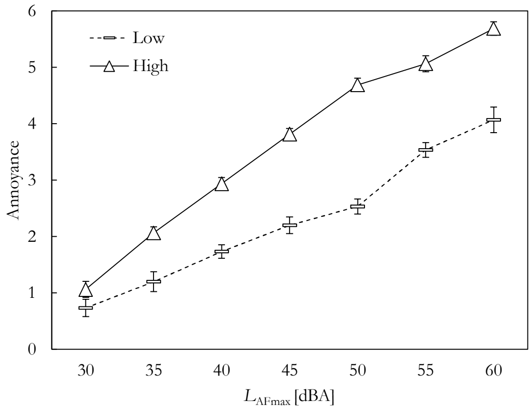


Figure 6-3. Annoyance compared between the low and high noise-sensitivity groups as a function of L_{AFmax}. Error bars indicate standard errors.

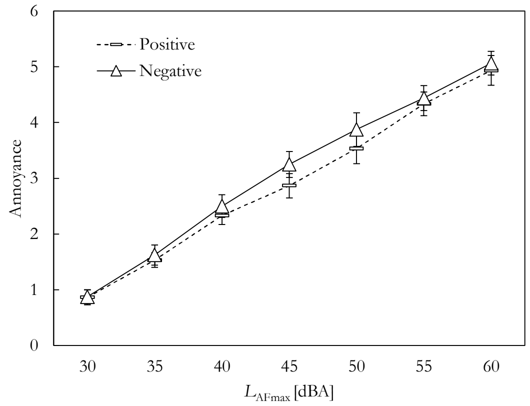


Figure 6-4. Annoyance compared between the positive and negative attitude groups as a function of L_{AFmax}. Error bars indicate standard errors.

Correlations of the emotion and annoyance ratings with the noise level and annoyance are presented in Table 6-9. The table also lists the correlations tested with all participant responses, with the noise-sensitivity groups and attitude groups. All emotions and annoyance ratings showed significant correlations with the noise level. All emotions showed significant correlations with annoyance. E4 was the only variable which had negative correlations with the noise level and annoyance, and it had lower coefficients than the other variables.

Table 6-9. Correlations of emotions (E1 ~ E4) and noise annoyance with (a) noise level and (b) annoyance. Coefficients are shown from the data of all participants, noise-sensitivity groups and attitude groups ($^{*}p < 0.05$, $^{**}p < 0.01$).

(a)		*n*	E1	E2	E3	E4	Annoyance
All participants (*N* = 41)			.628**	.701**	.638**	-.370**	.769**
Noise-sensitivity group	Low	15	.640**	.738**	.639**	-.257**	.800**
	High	16	.668**	.737**	.704**	-.432**	.769**
Attitude group	Positive	15	.515**	.593**	.515**	-.169*	.696**
	Negative	16	.720**	.804**	.743**	-.364**	.855**
(b)		*n*	E1	E2	E3	E4	Annoyance
All participants (*N* = 41)			.871**	.884**	.892**	-.660**	1
Noise-sensitivity group	Low	15	.867**	.871**	.810**	-.459**	1
	High	16	.812**	.845**	.779**	-.562**	1
Attitude group	Positive	15	.828**	.880**	.815**	-.448**	1
	Negative	16	.884**	.885**	.841**	-.442**	1

Figures 6-5 displays the relationships between the ratings of emotions (E1 ~ E4) and noise annoyance for the low and high noise-sensitivity groups. Further, Figures 6-6 presents the relationships between the ratings of emotions (E1 ~ E4) and noise annoyance for the positive and negative attitude groups. The E1 ~ E3 clusters contained negative emotions so they had positive correlations with noise annoyance, whereas the relationship between E4 and noise annoyance was negative. The figures describe that the participants with high noise sensitivity or negative attitude reported higher annoyance and negative emotions (E1 ~ E3). For example, the ratings of E1 for the high noise-sensitivity group ranged from 1.1 to 5.1, whereas those for the low noise-sensitivity group ranged from 0.5 to 4.0.

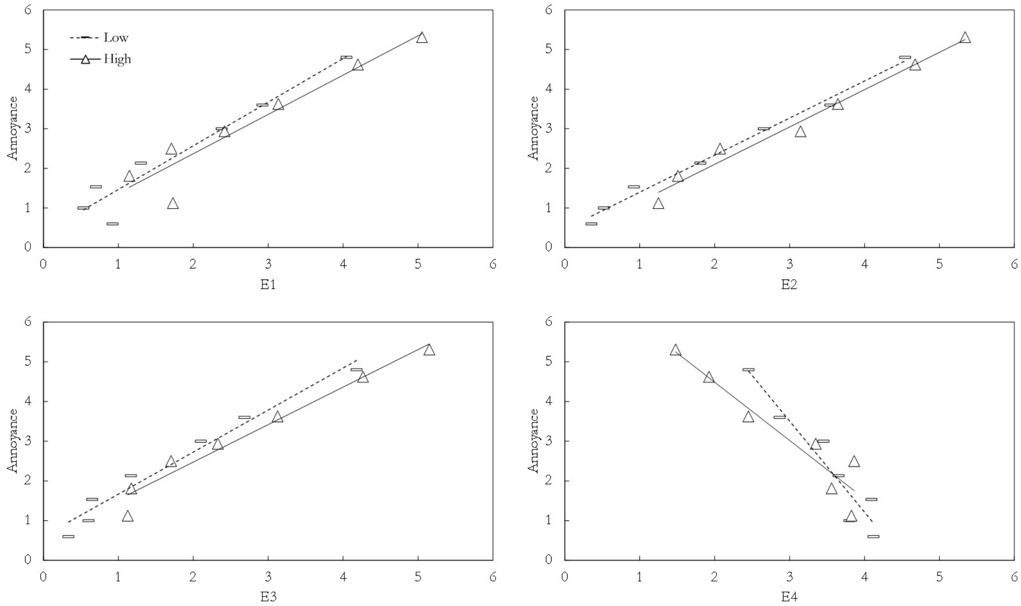


Figure 6-5. Relationships between noise annoyance and emotions compared between the low and high noise-sensitivity groups.

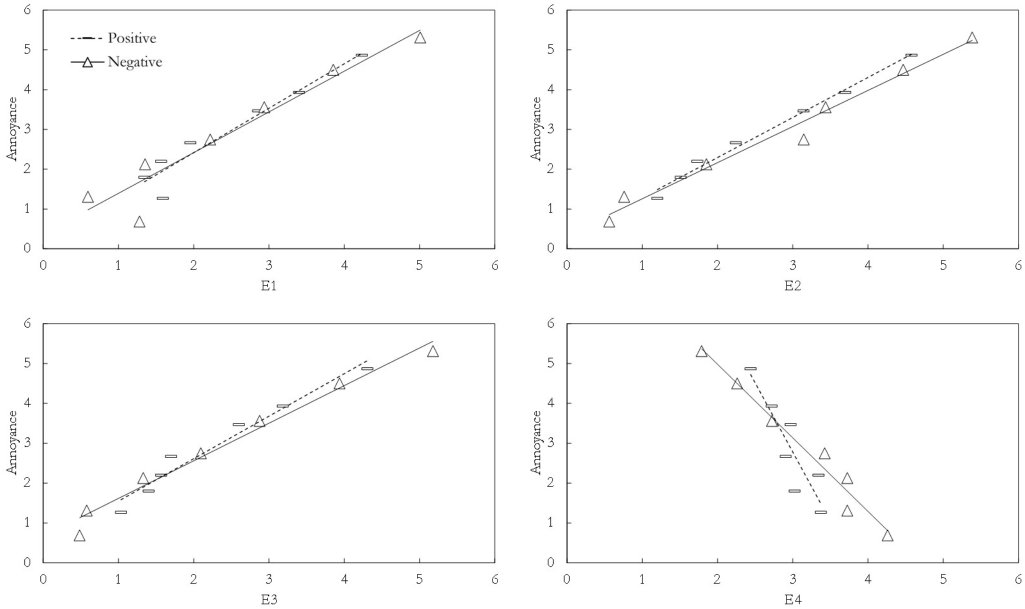


Figure 6-6. Relationships between noise annoyance and emotions compared between the positive and negative attitude groups.

Figure 6-7 illustrates the percentages of high emotion ratings (%HE1 ~ %HE4) as a function noise level, compared between the noise-sensitivity groups. For the high noise-sensitivity group, the percentage of highly rated E1 (%HE1) started to increase above 30 dBA, and it reached 100 % at 45 dBA. However, the low noise-sensitivity group's %HE1 remained at 0 % until 55 dBA. This indicates that participants who were sensitive to noise chose rating scores above the cut-off point (5 or 6 on a 7-point numerical scale), even at the low noise level such as 35 dBA. However, no one in the low noise-sensitivity group selected 5 or 6 even at 55 dBA. Similar tendencies were found in the E2, E3, and E4, showing huge differences between the noise-sensitivity groups. For example, when L_{AFmax} was at 50 dBA, the %HE2 and %HE3 were 100 % for the high noise-sensitivity group, whereas they were 0 % for the low noise-sensitivity group.

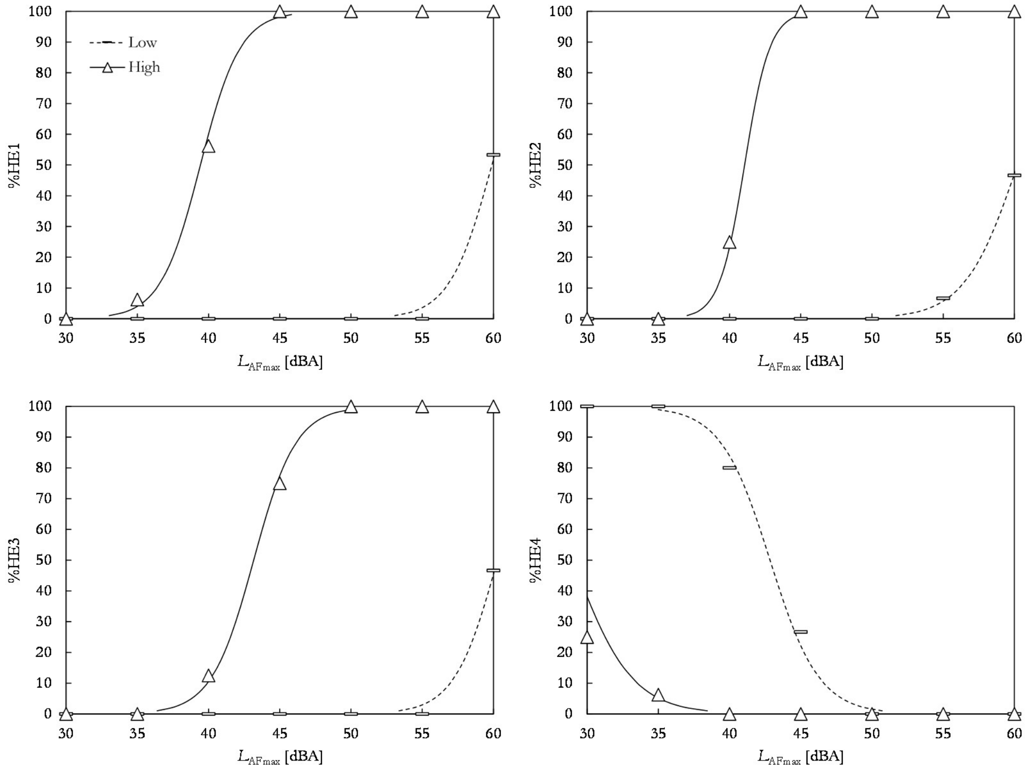


Figure 6-7. Percentage of high emotion ratings (%HE1 ~ %HE4) compared between the low and high noise-sensitivity groups as a function of L_{AFmax}.

Figure 6-8 illustrates the percentages of high emotion ratings (%HE1 ~ %HE4) as a function noise level, compared between the attitude groups. For the negative attitude group, %HE1 started to increase from 30 dBA, and it reached 90 % at 60 dBA. Likewise, those of high emotion ratings (%HE2 and %HE3) reported by the negative group reached above 90 % at 60 dBA. However, for the positive attitude group, the percentages of high emotion ratings for the negative emotions (%HE1 ~ %HE3) started to increase from 35 dBA and reached 60 % or 70 % at 60 dBA. Although the negative attitude group showed lower %HE4 than the positive group's ratings, there was no notable difference between the attitude groups.

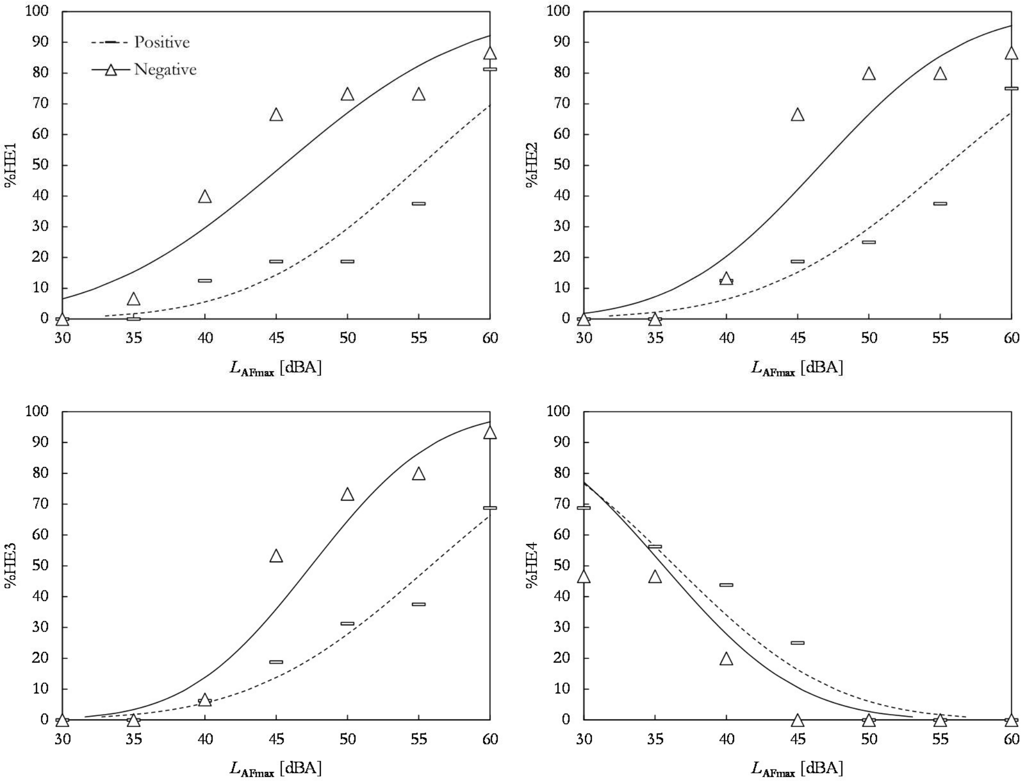


Figure 6-8. Percentage of high emotion ratings (%HE1 ~ %HE4) compared between the positive and negative attitude groups as a function of L_{AFmax}.

Figure 6-9 describes the percentages of highly annoyed (%HA) as a function noise level, compared between the noise-sensitivity groups. For the high noise-sensitivity group, the percentage of those who were highly annoyed (%HA) increased sharply in the region between 40 and 45 dBA, and it then reached 100 % at 50 dBA. In contrast, the %HA of the low noise-sensitivity group remained at 0 % until 45 dB, and it increased slowly above 50 dBA. Figure 6-10 presents %HA as a function noise level, compared between the attitude groups. Similar to the emotion ratings, the difference between the attitude groups was not as clear as that of the noise-sensitivity groups. Although the difference was not as huge, the negative attitude group still showed the higher %HA than the positive attitude group. It was found that %HA of both attitude groups started to increase from 35 dBA. The negative attitude group's %HA reached 100 % when the stimuli were played at 60 dBA while that of the positive attitude group reached 90 % at the same level.

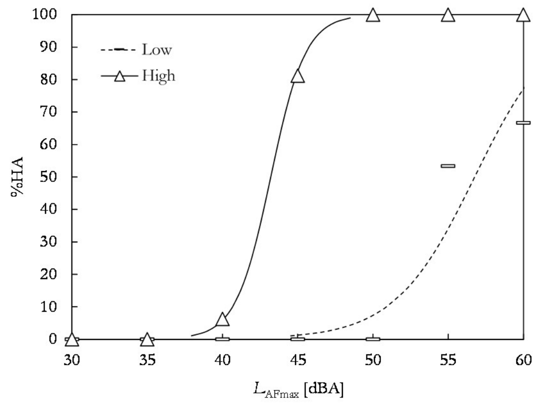


Figure 6-9. Percentage of highly annoyed (%HA) compared between the low and high noise-sensitivity groups as a function of L_{AFmax}.

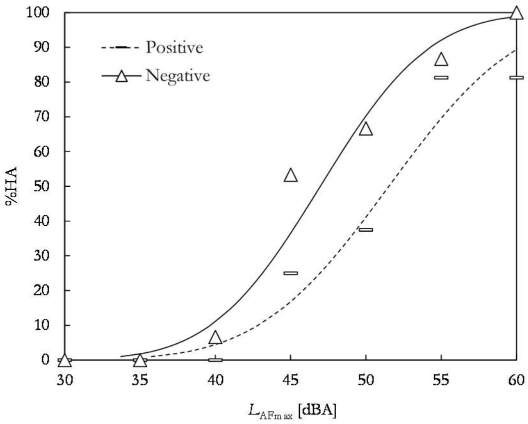


Figure 6-10. Percentage of highly annoyed (%HA) compared between the positive and negative attitude groups as a function of L_{AFmax}.

6.4 Discussion

6.4.1 The emotion clusters

As described by Roseman et al. (1990), emotion is caused by the way in which a person interprets a situation (i.e. appraisals). For instance, people feel pain or fear if they believe that they will not be able to resolve the negative situation satisfactorily (Harmon-Jones and Harmon-Jones, 2016). The four emotion clusters evoked by the floor impact noise may also have had such associations with appraisals. The first cluster, E1, which contained the largest number of lexicons, was related to anger and hostility mainly towards the noise source (i.e. upstairs neighbours). Anger is caused by a blocked goal (Lewis, 1993), which may cause the perception of the absence of a reward or the presence of a punishment (Roseman, 1991). Goal refers to an outcome that is personally significant (Lazarus, 1991; Scherer, 2001). If the noise of neighbours' footsteps has frequently disturbed residents' significant activities (i.e. goals) such as sleeping and studying (Park et al., 2016a), these experiences would lead to anger-related emotions. Anger is also linked with a specific appraisal of other-blame which is a belief that the unpleasant situation was wrongly caused by someone or something (Lazarus, 1991). The appraisal of other-blame contains a belief that the person causing the event acted in an improper or unfair manner (Shaver et al., 1987; Roseman, 1991). Thus, residents who appraise the noise event as their upstairs neighbours' fault or carelessness would be likely to perceive anger-related emotions towards their neighbours. Furthermore, residents may perceive anger-related emotions towards their neighbours if they believe the neighbours do not act appropriately or as expected (e.g. not apologising for being noisy or keep making noise). Noise-related crime among neighbours (Park, 2015a) could also be explained in relation to anger because this emotion motivates attack behaviours (Harmon-Jones and Harmon-Jones, 2016).

The lexicons in the E2 cluster were related to the emotions of dislike and irritation, mostly towards the situation of noise exposure. Most lexicons in this cluster were closely related to the E1 cluster on anger. For instance, Shaver et al. (1987) classified the lexicon 'irritation' under the prototype of 'anger'. However, this study discovered two differences between E1 and E2. First, the lexicons in E1 expressed emotions mainly towards neighbours, whereas those in E2 tended to target the situation of noise exposure. Second, the lexicons in E1 and E2 had different levels of arousal according to the structure of emotion which have been described on a circular model comprising two appraisal dimensions of arousal and valence (Russell, 1980; Watson and Tellegen, 1985; Larsen and Diener, 1992). According to the dimensional models, the lexicons in E1 and E2 had different levels of arousal. Lexicons in E1 contained relatively high arousal, whereas those in E2 had lower arousal. In this study, E2 also presented greater correlations with annoyance ratings than the other clusters. It is possibly due to the semantic similarity between the lexicon 'annoyance' and the lexicons in E2 such as 'bothered' or 'irritated'. Guski et al. (1999) previously studied the concept of noise annoyance in different languages and listed ten expressions which were rated similarly to 'annoyance'. Most of them overlapped with the lexicons in E2 such as 'get on my nerves', 'irritated', and 'vexed'.

The third cluster (E3) mainly contained lexicons expressing physical and emotional pains. Shaver et al. (1987) explored various lexicons expressing general emotions and grouped them into six prototype groups such as ‘anger’ and ‘sadness’. In particular, ‘sadness’ included a subgroup expressing pain such as ‘suffering’ and ‘hurt’. On the other hand, pain was one of the main emotion clusters in this study. The emotion lexicons expressing sadness were initially included in the 120 collected lexicons, but they were not chosen often by the respondents in Survey I. Consequently, those lexicons were not included in the 60 lexicons which were used in Survey II. It implies that the exposure to neighbours’ footstep noise may not elicit the emotion of sadness to a considerable extent. In contrast to the emotions in E1 and E2 which were found to target the noise source or the situation of noise exposure, the lexicons in E3 expressed the physical and emotional pain perceived by the respondents. For example, the lexicon ‘vengeful’ (E1) was directed towards the upstairs neighbours who made the noise, and the lexicon ‘unpleasant’ (E2) was directed towards the situation that the respondent was exposed to the noise. On the other hand, ‘feeling sick’ (E3) was an expression that described what the respondent felt or perceive inwardly. These findings are in line with the results of a previous study suggesting that neighbour noise evokes outwardly directed aggression and inward reactions such as tension and feelings of pressure (Grimwood, 1993). Given that many lexicons in E3 described physical pain (e.g. my head is throbbing, feeling sick, tired), this finding added further evidence to a previous finding that floor impact noise increases health complaints (Park et al., 2016a; Park et al., 2016b).

The fourth cluster (E4) contained lexicons describing empathy. Those expressions were narrated by residents who understood the situation of the noise event or their neighbours’ circumstances of making noise, or by those who did not care much about the noise exposure. According to Wispé (1986), empathy is a way of knowing, which is an attempt to understanding the subjective experiences of another person without prejudice. Empathy also covers the states of indifference or mere knowing and understanding (Darwall, 1998; Keen, 2006). Empathy has been suggested to weaken the response of annoyance and vigilance coping strategies (Park et al., 2016a). Thus, respondents who tended to report higher ratings on the empathy-related lexicons might have also reported relatively lower annoyance ratings. Moreover, it is unlikely for them to choose vigilance coping strategies, as it may lead to conflicts with their neighbours (Park et al., 2016a). This is in agreement with the suggestion made by Zaki and Ochsner (2016). They suggested that individuals often want to approach empathy when it facilitates important social goals, such as relationship formation and maintenance. Here in this study, the relationship between neighbours can be considered as a variable that has a strong influence on empathy. It was previously proposed that the relationship with one's neighbours is an intervening condition that influences one's perception of noise events (Park et al., 2016a). It can be assumed that residents who have positive relationships with their neighbours may say 'there is no reason to get angry' (E4) regarding their neighbour noise. In such situations, empathy develops with the influence of a positive relationship with one's neighbours. However, some intervening conditions may also decrease people's empathy when it is painful or costly (Zaki and Ochsner, 2016).

Several studies have conducted questionnaire surveys and laboratory experiments to evaluate noise annoyance. These methods have been widely used to evaluate the adverse effect of noise on both individuals and communities (Guski, 1999; Guski et al., 1999; Stansfeld et al., 2000). However, in the case of neighbour noise, it is appropriate to measure emotions because neighbour noise is likely to result in neighbour disputes including violence (Stokoe and Hepburn, 2005; Park, 2015a; Park et al., 2016a) and also annoyance cannot adequately explain or predict potential disputes or relational problems between neighbours. Therefore, the measurement of emotions expressed towards the neighbour (E1) and the situation of noise exposure (E2) would be of use to predict their coping strategies in future research. If future research needs to choose only parts of the four emotion clusters to conduct more prompt measurements, this study would suggest choosing E1 and E4 for the following reasons. First, given that emotion measurements aim to predict respondents' internal perceptions and future coping strategies, anger needs to be measured, particularly in the case of noise issues between neighbours because it is an emotion which may develop into violent behaviours (Harmon-Jones and Harmon-Jones, 2016). Second, empathy needs to be assessed to predict future coping strategies as empathy leads individuals to build or maintain positive relationships with others (Zaki and Ochsner, 2016). In particular, this study presented that empathy had the weakest correlation with annoyance. Since the measurement of annoyance cannot predict empathy, it needs to be assessed to yield an extended insight into respondents' perception and to predict their future coping strategies. Third, emotions related to dislike (E2) can be excluded because it is strongly correlated with annoyance and most of the lexicons in E2 were suggested to be semantically similar to annoyance (Guski et al., 1999). Fourth, the lexicons in E3 described pain, but as discussed earlier, some of them rather referred to health complaints.

6.4.2 Effects of noise sensitivity and attitude towards neighbours

As noted in the section above, intervening conditions cannot be overlooked when it comes to considering emotions. Intervening conditions influence the procedure of appraisal which evokes emotions (Roseman et al., 1990). This study tested two intervening conditions which were introduced in the previous study (Park et al., 2016a): noise sensitivity and attitude towards neighbours. Guski (1999) also emphasised that noise sensitivity, personal evaluations of the source, coping capacity, general attitude, history of noise exposure, and residents' expectations have important impacts on noise annoyance. First, this study found notably different trends between the noise-sensitivity groups supporting previous findings. Ryu and Jeon (2011) highlighted a significant impact of noise sensitivity on the annoyance evoked by indoor residential noises. The previous experiment (Chapter 5) also addressed significant differences in the floor impact noise annoyance between the low and high noise-sensitive participants. Similarly, this study revealed significant differences between the noise-sensitivity groups, which implied that the higher noise sensitivity would influence individuals' appraisals to perceive higher anger, dislike, and pain, whereas low noise sensitivity may lead to a more empathetic appraisal of the event. Second, this study also showed that attitudes towards neighbours had an influential role in the emotion-evoking and annoyance-evoking appraisals. This study found that the participants with positive attitudes towards their upstairs neighbours provided lower negative emotion ratings (E1 ~ E3), lower annoyance ratings, and higher empathy (E4). This result was in line with the findings of Pedersen and Persson Waye (2007), who revealed that negative attitudes towards wind turbines influenced the wind turbine noise annoyance. Since the results showed the impacts of the attitude not as clear as those of the noise sensitivity, further examination is recommended to assess one's attitude towards his/her neighbours.

6.4.3 General discussion

Namba et al. (1991) previously used lexicons in their study to measure the impressions of sound stimuli. In particular, they collected a pool of Japanese adjectives from a preliminary experiment, but details about the experimental procedure (e.g. level of the stimuli) and main findings (e.g. the number of adjectives) of the preliminary study were not explained. In this study, the appropriate lexicons were collected carefully from two sources: interview transcripts from a previous study (Park et al., 2016a) and a number of posts on online communities. The interview transcripts were chosen as one of the sources because the interviews were conducted using grounded theory methods. Utilising the grounded theory methods, the interviews were conducted until the author was confident that no more new findings could be obtained so that theoretical saturation was attained (Corbin and Strauss, 2008). Therefore, it was assumed that the interview transcripts included most of the possible aspects of footstep noise and residents' emotional expressions towards the noise. This study also collected a number of online posts from 18 online communities. From the posts, only lexicons expressing emotions evoked by footstep noise were gathered. Therefore, it can be said that the collected lexicons represented the narratives of residents adequately, particularly regarding the footstep noise of neighbours.

During the two online surveys, the respondents were asked to listen carefully to the noise via headphones. It was not possible to control the quality of sound reproduction, noise level, and background noise level. In particular, most headphones are limited to reproducing low-frequencies below 50 Hz. Thus, these practical constraints might have influenced the survey respondents' responses. However, all participants had experienced being exposed to footstep noise from their upstairs neighbours. So they were expected to rate the lexicons based on not only the presented noise stimuli but also their previous experiences of noise exposure. The sound reproduction system using the loudspeaker and subwoofer in the laboratory setting was considered to be useful to fill the gap in the findings of people's emotions because the low-frequency components could be presented in the experiments.

Based on the findings in this study, the following recommendations for future research are made. First, it would be useful to explore the emotions evoked by different types of noise. For instance, neighbour noise comprises several other noise sources. Emotions evoked by other types of floor impact noise (e.g. a chair or furniture scraping) or airborne noise (e.g. voice or conversations of neighbours) can also be examined to identify any influences of different noise sources. Moreover, it can be assumed that different floor materials, shoe types, and body sizes would cause different footstep noises (Turchet et al., 2016). Thus, the use of different footstep noise stimuli may yield noteworthy insights. Furthermore, the concept of total annoyance can be utilised in future neighbour noise studies. It is known that the annoyance response to a single noise source and the total annoyance evoked by combined noises are different to each other (Öhrström et al., 2007; Jeon et al., 2010a). Likewise, it can be assumed that the annoyance and emotional responses evoked by combined floor impact noises or neighbour noise would be different from those evoked by different single sources (e.g. footsteps, dropping of objects). For example, a general floor impact noise (i.e. combined) may elicit higher anger and annoyance than exposure to footstep noise alone or the opposite result may be found. Second, there are several emotion lexicons in different languages and they contain different nuances of emotions. The investigation into cultural differences in emotion will also provide further evidence (Watson et al., 1984; Grossmann et al., 2012). Given that neighbour noise is not a problem in Korea alone, emotion research using lexicons in different languages and cultures would be of help to understand the emotional responses to neighbour noise in a broader sense. Third, different attempts could be made to evoke emotions. Participants are highly likely to become passive observers if they receive one-way, simplified, and well-controlled stimuli (Hari et al., 2015) because human emotions naturally occur in interaction with others and external events (Gilam and Hendler, 2016). As this study simply presented the stimuli and did not ask participants to engage or interact with anything, the participants might have responded to the questionnaire as passive observers. Thus, it is difficult to define to which extent emotions were resulted by the stimuli, and this study may have missed some important emotional processing factors (Hari et al., 2015). Further consideration of methods for evoking emotional responses to neighbour's noise in a more engaging and ecological way could be examined in the future (Schmidt et al., 2018). Fourth, different methods could be used to measure emotions. Emotion lexicons are linguistic expressions, so there is a possibility that they could be either understated or overstated by the respondents. Moreover, emotion lexicons may not fully reflect the perceivers' true emotional status, especially if they are not aware of their real inward feelings. Therefore a questionnaire survey can be carried out along with measurements of physiological responses because the brain and bodily functions are strongly synchronised by emotion-evoking stimuli (Hari et al., 2015). In addition, assessments in performance may be of use to understand the subjective states of participants. One of the important advantages of the performance evaluation is that demanding tasks elicit various stress responses, such as anxiety and worry, which facilitates an examination of subjective states (Matthews et al., 2002). Therefore, future research could adopt physiological measurements or performance evaluation, or both to assess subjective states before and after eliciting emotional experiences through the noise.

6.5 Summary

In this study, lexicons expressing emotions evoked by neighbours' footstep noise were collected. The emotional responses were assessed when the participants were listening to the noise stimuli. Throughout the study, the footsteps of a child and an adult were presented as the noise stimuli. First, a total of 120 Korean lexicons were chosen from interview transcripts and online community posts. The number of lexicons was reduced to 60 through an online survey. Participants of the first survey (N = 133) were asked to choose appropriate lexicons expressing their emotions while they were listening to the noise stimuli. Subsequently, another online survey was conducted with 89 participants, who rated the appropriateness of each lexicon while they were listening to the noise stimuli. Based on their responses, the lexicons were classified into four clusters: anger, dislike, pain, and empathy. In the laboratory experiment, 20 lexicons were listed to the participants (N = 41) who rated each lexicon during the noise exposure. Noise stimuli were played at noise levels between 30 and 60 dBA (L_{AFmax}) with 5 dB intervals. Emotion and noise annoyance were significantly affected by the noise level, indicating that the greater noise level led to greater negative emotions and annoyance ratings. The three emotion clusters representing negative emotions were strongly correlated with noise annoyance. The emotion cluster of 'DISLIKE' (E2) had the strongest correlation with noise annoyance, whereas the cluster of 'EMPATHY' (E4) showed the weakest correlation with noise annoyance. This study also revealed that noise sensitivity and attitudes towards neighbours moderated the emotion and annoyance ratings. Overall, the findings suggested that low noise level, low noise sensitivity, and positive attitudes towards neighbours would lead to less negative emotions and annoyance when neighbours' footstep noises are heard. Table 6-10 summarises the major findings of this study with the research questions of the study.

Table 6-10. The research questions and the findings of this study.

Research questions	Findings
▪ How do people respond to floor impact noise psychologically and physiologically?	▪ Annoyance (increase) ▪ Emotions - Anger (increase) - Dislike (increase) - Pain (increase) - Empathy (decrease)
▪ What factors have impacts on the responses?	▪ Noise level increased the responses. ▪ Greater responses were shown by the participants with higher noise sensitivity. ▪ Greater responses were shown by the participants with negative attitudes towards their neighbours. However, the difference between the positive and negative attitude groups was but not as significant as that of the noise-sensitivity group.

7 Psychological responses to indoor noise and its relationship with various factors: A field study[*]

7.1 Introduction

This study was conducted *in situ* in order to validate the findings in earlier chapters. The study also aimed to explore the effects of various acoustic and non-acoustic factors on residents' psychological responses to floor impact noise. Furthermore, it examined adverse health effects of floor impact noise exposure. The study was conducted at four different apartment complexes with one hundred residents from each complex ($N = 400$). The participants responded to a questionnaire which measured their psychological responses to indoor noise. The questionnaire assessed their self-reported annoyance, anger, and empathy evoked by floor impact noise. Anger and empathy were two of the four emotions found in the previous study (Chapter 6). Additionally, the questionnaire measured self-reported satisfaction with indoor noise environment. Various factors were tested to examine whether they had significant relationships with the psychological responses

---

[*] This chapter has been partly published in a peer-reviewed journal and a conference proceeding. The papers can be found in Appendix 7.

to indoor noise. The tested factors included personal factors (e.g. socio-demographic characteristics), characteristics of the house (e.g. slab thickness), characteristics of the floor impact noise (e.g. major noise source), and characteristics of outdoor noise (e.g. outdoor noise level), and annoyance of the outdoor noise (e.g. road traffic noise annoyance). Particularly, the outdoor noise was concerned because it was assumed it might mask indoor noise. Outdoor noise measurements were carried out for 24 hours on top of buildings at each site in order to generate the noise maps and to predict façade noise levels of each housing unit. The participants' self-reported quality of life and blood pressure were measured to evaluate the adverse effects of floor impact noise on the residents' health and well-being. The study was conducted based on the following research question and objectives as shown in Table 7-1.

Table 7-1. The research question and objectives of the present field study.

Research questions	Objectives
▪ What factors have effects on the responses to floor impact noise?	▪ To investigate the impacts of the following factors on the responses: - Personal factors: socio-demographic characteristics, length of residency, and self-reported noise sensitivity. - Characteristics of the house: slab thickness, age of the building, and net floor area of the house. - Characteristics of the floor impact noise: major noise source, child(ren) upstairs, and time of noise exposure. - Outdoor noise: distance from the road, distance from the railway, outdoor noise level, annoyance caused by road traffic noise and railway noise, and total annoyance.

7.2 Methods

7.2.1 Sites

As listed in Table 7-2, four apartment complexes in Gyeonggi province of South Korea were recruited in the study. The oldest site was built in 1994 (Site A) and the newest one was built in 2014 (Site D). The tallest building was at Site A (25 floors). The biggest site had 1,827 houses (Site A), whereas the smallest one had 262 houses (Site C). Slab thickness of the apartments varied: 150 mm slabs were used in Sites A and B, 180 mm in Site D, and 210 mm in Site C. Net floor area of the residences also varied from 52 m^2 (in Site D) to 157 m^2 (in Site C). The average price per square metre of residences in Site A was the highest but the properties at Site C were the most expensive due to the bigger size of the residences. Site D was a type of public rental housing which was owned by the government and offered with a long-term rent plan. Thus, there was no information about the average price per square metre for Site D. This study aimed to minimise the variations of factors affecting floor impact noise levels. First, all the buildings had the same structure which is a box-frame-type reinforced concrete construction. Secondly, the buildings with similar floor structures were chosen. The floors consisted of the reinforced concrete slab, resilient material, lightweight concrete, and finishing mortar (Appendix 5). All the resilient materials were Expanded Polystyrene (EPS) and thicknesses of the materials varied from 20 to 30 mm.

Table 7-2. Information of the participated sites.

	Site No.			
	A	B	C	D
Construction year	1994	2002	2009	2014
Number of buildings	21	7	7	8
Number of residences	1,827	583	262	522
Maximum number of floors	25	23	15	18
Slab thickness [mm]	150	150	210	180
Net floor area of the residences [m^2]	58 ~ 85	84	107 ~ 157	52 ~ 60
Average price per m^2 [GBP][a]	2,533	2,127	2,047	·

[a] South Korean Won (KRW) was converted to British Pound (GPB) with an exchange rate of GBP 1 = KRW 1,500

7.2.2 Participants

One hundred residents from each site took part in the study so a total of 400 participants were recruited. None of the participants had hearing disabilities. There were inclusion criteria for participant recruitment. Participants should (1) be

South Koreans, (2) be residents of the site in which the study was carried out, (3) have self-reported normal hearing, (4) have their body mass index in the normal range (18.5 ~ 25 kg/m^2), (5) not have any history of cardiovascular, respiratory (asthma), musculoskeletal disorders, diabetes mellitus, epilepsy, and hearing disabilities, (6) not currently take any heartbeat-affecting drug, (7) not have any past experience of being professional athletes, (8) have diastolic blood pressure between 60 and 90 mmHg and systolic blood pressure between 90 and 140 mmHg, and (9) be between the ages of 20 and 60. The criteria from #4 to #9 were adopted in order to collect the blood pressure data within the normal range and to control any potential impacts of factors which could affect blood pressure.

Age of the participants ranged from 20 to 60 and the mean age of the whole participants was 42.9 years old (*SD* = 10.5). Male and female participants were recruited almost evenly from each site. More than half of the participants from Sites A and C reported that they did not live with any child. More than half of the participants from Sites B and C reported that there were one or more children living upstairs. Although the questionnaire gave five options for the education level (primary school; middle school; high school; university/college; postgraduate), there was no participant chose either the option of primary or middle school. Most of the participants' education level was at the university/college level. The majority of the participants were employed and most of them were employed full-time. Length of residency ranged from 2 months to 277 months (23 years and 1 month) which partially correlated with the age of the building. Most of the participants from Sites A, B, and C reported that they owned their houses, whereas all the participants from Site D rented their houses from the government. Table 7-3 lists the information about the participants.

Table 7-3. Information of the participants (*N* = 400) from each site.

			Site No.			
		Whole	A	B	C	D
Age [year]	*M*	42.9	44.3	41.6	42.5	43.4
	SD	10.5	9.6	11.2	10.5	10.6
Gender [*n*]	Male	192	45	46	56	47
	Female	208	55	54	44	53
Education level	High school	73	17	22	13	21
	University/college	293	80	65	74	74
	Postgraduate	34	3	13	13	5
Annual household income [GBP][a]	< 13,330	3	1	0	2	0
	13,330 ~ 19,990	38	10	1	16	11
	19,990 ~ 26,660	66	20	3	26	17
	26,660 ~ 33,330	111	35	7	33	36
	33,330 ~ 39,990	104	24	35	18	27
	39,990 <	78	10	54	5	9
Child(ren) at home [*n*]	Yes	177	30	58	39	50
	No	223	70	42	61	50
Child(ren) upstairs [*n*]	Yes	218	50	61	59	48
	No	114	35	24	27	28
	Don't know	68	15	15	14	24
Length of residency [month]	*M*	85.4	141.1	107.6	59.2	33.7
	SD	62.8	78.3	42.5	29.0	9.4
House ownership [*n*]	Owner	271	90	94	87	0
	Renter	129	10	6	13	100

[a] South Korean Won (KRW) was converted to British Pound (GPB) with an exchange rate of GBP 1 = KRW 1,500

7.2.3 Questionnaire

The questionnaire was divided into five main sections. The first section of the questionnaire asked the participants to give brief details about themselves and their houses. The participants were asked about their age, gender, education, income, child(ren) at home, length of residency, the net floor area of the residence, and house ownership. This section of the questionnaire also measured self-reported noise sensitivity using 21 question items (Weinstein, 1978). The second section dealt with the participants' psychological responses to indoor noise. The level of annoyance caused by floor impact noise was assessed. Noise annoyance was rated using an 11-point scale (0 = '*Not at all*' and 10 = '*Extremely*') as recommended in Fields et al. (2001) and the ISO/TS 15666. The participants were provided with the following instruction: "Thinking about the last 12 months or so, when you are in your home, how much does floor impact noise annoy you?" Besides, emotions (anger and empathy) evoked by the floor impact noise were assessed using the lexicons developed in Chapter 6. In this study, only anger and empathy were measured based on the suggestion made by Chapter 6. The participants were asked to rate the emotions on 7-point scales (0 = '*Not at all*' and 6 = '*Extremely*') according to the following instruction: "Please rate how much each lexicon is appropriate for expressing your emotions perceived towards the floor impact noise you have heard for the last 12 months." For those who had lived in their current houses for less than 12 months, they were asked to think about the period of time that they had lived in the current house. Moreover, perceived satisfaction with the general indoor noise environment was asked using an 11-point scale (0 = '*Not at all*' and 10 = '*Extremely*') with the following instruction: "Please rate how much you are satisfied with the indoor noise environment in your home." The third section of the questionnaire measured characteristics of the floor impact noise exposure. Question items asking the major noise source, any child(ren) upstairs, and time of the noise exposure were used. For the major noise source, the question listed six noise sources adopted from the previous study (Chapter 3). The noise sources included two heavyweight impact noise sources (children's footsteps and adults' footsteps) and four lightweight impact noise sources (scraping of furniture, dropping of objects, door banging, and plumbing system). The questionnaire also asked whether there was any child living upstairs since the footstep noise of children has been known to be the dominant noise source in apartment buildings (Jeon et al., 2006a). In order to measure the time of noise exposure, the following five options were given: 06:00 ~ 09:00, 09:00 ~ 12:00, 12:00 ~ 18:00, 18:00 ~ 20:00, and 20:00 ~ 06:00. The fourth section of the questionnaire was to measure the annoyance of outdoor noise. The participants were asked to rate perceived annoyance caused by outdoor road traffic noise and railway noise. In addition, total annoyance regarding the general outdoor noise was measured. All questions were given with 11-point scales (0 = *'Not at all'* and 10 = *'Extremely'*). The last section of the questionnaire measured the participants' self-reported quality of life using 36 question items (Ware Jr and Sherbourne, 1992; McHorney et al., 1993; McHorney et al., 1994). The measurement of the quality of life was comprised of two major components: physical health and mental health-related quality of life.

7.2.4 Outdoor noise measurements

Residents in multi-family housing are exposed to not only indoor building noise (e.g. floor impact noise) but also outdoor noise (e.g. road traffic noise) in their homes. This study assumed that the outdoor noise level might have masking effects on the indoor noise and thereby the psychological responses to floor impact noise might be affected (Kryter, 1970). There were traffic roads near all the sites. Sites A and B were nearby roads with three or more lanes, while Sites C and D were close to roads with a smaller number (e.g. one or two) of lanes. Sites A, B, and C were located in the vicinity of railways so they were exposed to the railway noise also. Outdoor noise measurements were carried out on top of buildings in each site for 24 hours on one weekday. Five buildings in Sites C and D, four buildings in Site B, and three buildings in Site A were chosen for the noise measurements. The number of buildings where the noise measurements were conducted at each site was different due to the different regulations of the sites. All sound level metres (SVAN 943, Svantek) were mounted on the tripods and positioned 1.2 m above the ground. Table 7-4 lists $L_{\mathrm{Aeq,24\text{-}hour}}$ and the L_{dn} measured from the top of the buildings of each site. Noise maps were generated (Appendix 5) using SoundPLAN, based on the data collected from the noise measurements and measured traffic flow from the

Korean Government (http://viewt.ktdb.go.kr). The predicted noise levels showed good agreements with the measured noise levels within 3 dB. The façade noise maps were generated to predict the noise exposure of each housing unit.

Table 7-4. L_{Aeq} and L_{dn} recorded from the top of the buildings from each site.

Site	Building	$L_{Aeq,24\text{-hour}}$	L_{dn}
A	1	57.0	61.0
	2	45.0	49.2
	3	50.6	54.4
B	1	61.0	65.7
	2	59.0	63.6
	3	55.5	59.7
	4	54.0	58.5
C	1	64.8	68.1
	2	57.7	61.2
	3	56.0	59.7
	4	53.9	57.8
	5	52.0	56.2
D	1	50.3	54.0
	2	47.1	51.0
	3	44.0	48.2
	4	40.6	45.0
	5	39.2	43.8

7.2.5 Procedure

Only those who met the inclusion criteria and provided their consent participated in the study. The participants took part in the study individually. Each participant was invited to visit the designated place in each site to take part in the study. It was located in the management office building at each site so the participants were well aware of where the location was. The participant information sheet and a written consent form were provided to the participant upon arrival. Before obtaining the consent, the author explained the purpose of the study and answered the participant's questions. The participant was assured of complete anonymity. After that, the participant was asked to complete the questionnaire.

Blood pressure was measured from the participant's left arm using the blood pressure monitor (Omron M3 Comfort, HEM-7134-E). The author helped the participant to sit on a chair in a correct posture (sitting upright with the back straight and legs uncrossed) and to rest his/her left arm comfortably at heart level. Any tight-fitting or thick clothing was removed from the arm before the measurement. Each participant received KRW 10,000 (approximately GBP 7) gift card for the participation.

7.2.6 Data analysis

Statistical analyses were performed using SPSS for Windows (version 22). Bivariate (Pearson) correlations were assessed between two variables. Impacts of the factors were tested with the one-way ANOVA and group differences were examined using the independent samples *t*-tests. The multiple linear regression analyses were performed to examine which factors significantly predict the subjective responses to the noise and health consequences. *p* values of less than 5 % ($p < 0.05$) were considered as statistically significant.

7.3 Results

Correlations between various factors and the participants' self-reported annoyance, anger, and empathy perceived towards floor impact noise and satisfaction with indoor noise environment were evaluated. First, several personal factors were examined; age, education level, income, length of residency, and self-reported noise sensitivity. Second, the characteristics of the house were assessed: slab thickness, age of the building, and the net floor area of the house. Third, the characteristics of the outdoor noise were studied: the distance from the road, distance from the railway, and the outdoor noise levels predicted in each house in terms of the L_{dn}. Fourth, as the participants' annoyance of the outdoor noise, annoyance caused by road traffic noise and railway noise, and total annoyance were examined. Fifth, the participants' perceived quality of life in regard to physical health and mental health were evaluated. Finally, the participants' diastolic and systolic blood pressure were tested. As Table 7-5 shows, some of the factors had statistically significant correlations with the psychological responses to indoor noise. In addition to the analyses on the correlational relationships, group comparisons were performed in order to further explore the effects of the factors. Differences between groups were tested using the factors which had significant correlations (e.g. between low and high noise-sensitivity groups) or those of which correlations could not be tested because they were measured as nominal or categorical data (e.g. gender and house ownership).

Table 7-5. Correlations of annoyance, anger, empathy, and satisfaction with various tested factors (*$p < 0.05$, **$p < 0.01$).

		The whole participants' responses ($N = 400$)			
		Annoyance	Anger	Empathy	Satisfaction
Personal factors	Age	-.099*	-.115*	.077	.110*
	Education level	.027	.017	-.031	-.014
	Income	.028	-.043	.167**	.019
	Length of residency	.058	.077	-.042	-.026
	Noise sensitivity	.828**	.845**	-.710**	-.858**
Characteristics of the house	Slab thickness	-.038	.013	-.204**	-.013
	Age of the building	.121*	.191**	-.151**	-.101*
	Net floor area of the house	.032	.096	-.134**	-.035
Characteristics of the outdoor noise	Distance from the road	-.036	-.120*	.133**	.012
	Distance from the railway	-.063	-.102	.149**	.049
	Outdoor noise level (L_{dn})	.077	.113*	.016	-.033
Perceptions of the outdoor noise	Road traffic noise annoyance	.434**	.444**	-.269**	-.396**
	Railway noise annoyance	.397**	.473**	-.422**	-.385**
	Total annoyance	.580**	.626**	-.469**	-.559**
Health consequences	Physical health-related quality of life	-.142**	-.168**	.150**	.157**
	Mental health-related quality of life	-.251**	-.255**	.230**	.254**
	Diastolic blood pressure	.724**	.729**	-.582**	-.707**
	Systolic blood pressure	.714**	.750**	-.603**	-.712**

7.3.1 Personal factors

Among the socio-demographic characteristics, age showed significant correlations with the annoyance, anger, and satisfaction but the correlation coefficients were low (Table 7-5). Education level did not correlate with any of the responses, while income had a significant but weak correlation with empathy. Length of residency also did not have any correlation with the responses. There were some other socio-demographic characteristics measured as nominal or categorical data: gender, child(ren) at home, and house ownership. Their impacts were tested by group comparisons. First, it was found that the female participants reported higher annoyance and anger ratings than the male participants but there was no significant difference between the responses between males and females. Likewise, the male participants reported higher satisfaction than the female participants but the difference was not significant. Moreover, both male and female participants' empathy ratings were very similar to each other (M = 3.302 and 3.298, respectively). Second, those who lived with one or more children reported lower annoyance and anger than those who did not have any children but there was no difference between them. Similarly, those who had one or more children also reported higher empathy and satisfaction than those who did not have any children but there was no significance in the difference. Third, there were significant differences between the house owners and renters in some responses. Figure 7-1 illustrates that the house owners reported higher annoyance and anger, whereas the renters reported higher empathy and satisfaction. There were significant differences in the three psychological responses concerning floor impact noise (annoyance, anger, and empathy ratings). However, there was no significant difference in the responses of satisfaction with indoor noise environment.

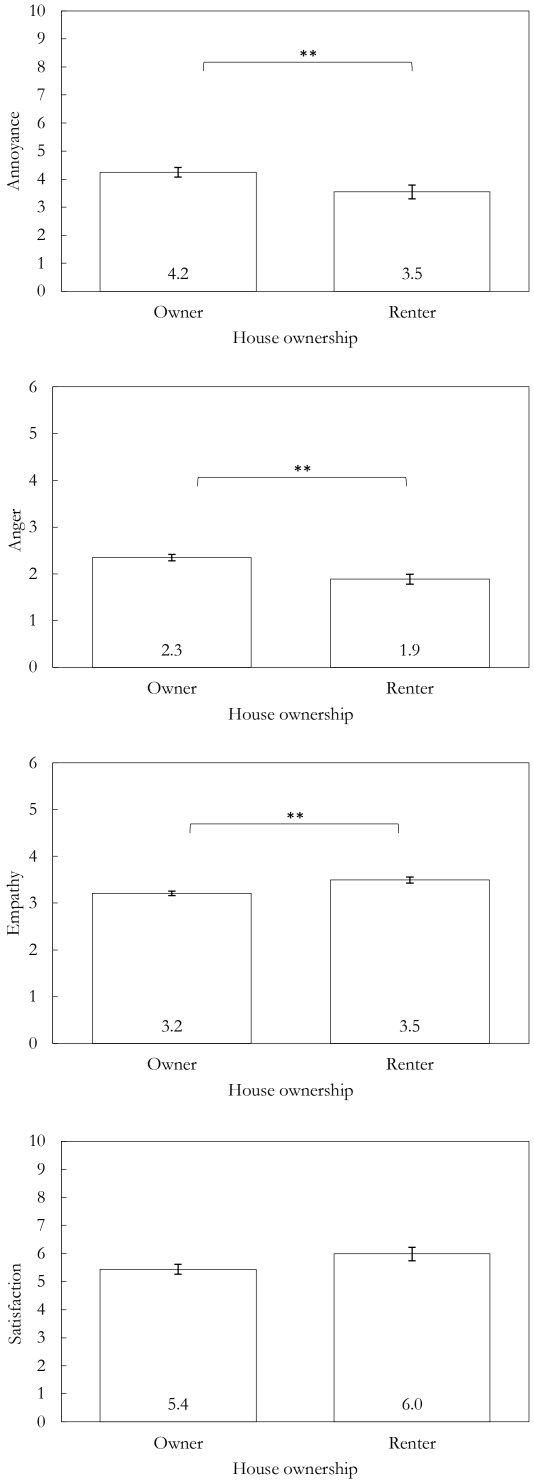


Figure 7-1. Annoyance, anger, empathy, and satisfaction compared between the house owners and renters. Error bars indicate standard errors (*$p < 0.05$, **$p < 0.01$).

As presented in Table 7-5, noise sensitivity significantly correlated with annoyance ($r = .83$), anger ($r = .85$), empathy ($r = -.71$), and satisfaction ($r = -.86$). The effects of the noise sensitivity on the responses were examined using the one-way ANOVA. The results showed that noise sensitivity had significant impacts on annoyance [F (60, 339) = 26.05, $p < 0.01$)], anger [F (60, 339) = 18.77, $p < 0.01$)], empathy [F (60, 339) = 8.52, $p < 0.01$)], and satisfaction [F (60, 339) = 31.14, $p < 0.01$)]. The responses were then compared between those who reported low noise sensitivity with those who reported high noise sensitivity. The participants were split into two groups concerning their noise-sensitivity scores. The mean and median noise-sensitivity scores of the whole participants were 79.4 and 79.0, respectively. The median value was used as a cut-off point to divide the participants into two groups. The participants whose noise-sensitivity scores were <= 79 were grouped as the low noise-sensitivity group (n = 204) and those with noise-sensitivity scores above 79 were grouped as the high noise-sensitivity group (n = 196). The low noise-sensitivity group's mean noise-sensitivity score was 68.6 (SD = 7.3) and the high noise-sensitivity group's mean noise-sensitivity score was 90.6 (SD = 7.7). As described in Figure 7-2, the high noise-sensitivity group had higher annoyance and anger ratings than the low noise-sensitivity group, while their empathy and satisfaction ratings were lower than those of the low noise-sensitivity group. The responses of the two groups were significantly different.

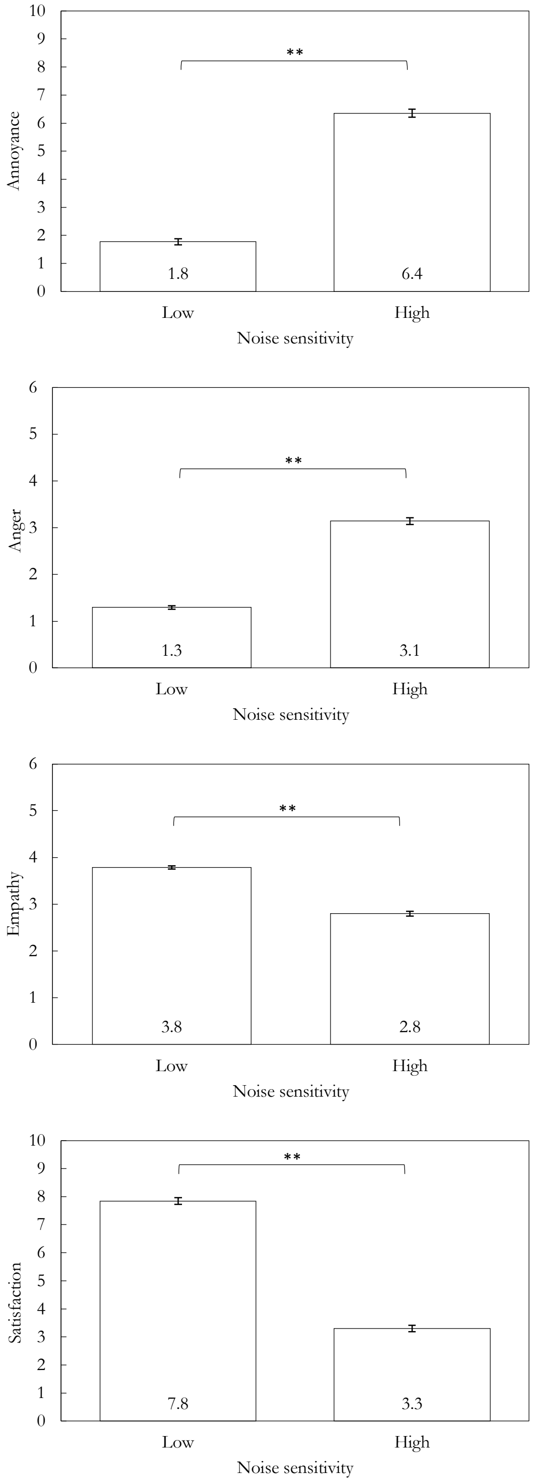


Figure 7-2. Annoyance, anger, empathy, and satisfaction compared between the low and high noise-sensitivity groups. Error bars indicate standard errors (*$p < 0.05$, **$p < 0.01$).

7.3.2 Characteristics of the house

The psychological responses to indoor noise were compared between the four sites (Sites A ~ D) as presented in Figure 7-3. The annoyance rating of Site A was the highest (*M* = 4.5; *SD* = 3.4), whereas Site D reported the lowest annoyance (*M* = 3.4; *SD* = 2.6). Only the annoyance ratings between Sites A and D were significantly different. Similarly, Sites A and D showed the highest (*M* = 2.6; *SD* = 1.3) and lowest (*M* = 1.7; *SD* = 1.1) anger ratings, respectively. There were significant differences in the anger ratings between Sites A and B, Sites A and D, and Sites C and D. Empathy reported by the participants in Site B was the highest, followed by those in Sites D, A, and C. Significant differences in the empathy ratings were found between Sites A and B, Sites A and D, Sites B and C, and Sites C and D. For the satisfaction with indoor noise environment, the highest satisfaction was reported from Site D, followed by Sites B, C, and A. Only the satisfaction ratings of Sites A and D were significantly different.

As listed in Table 7-5, slab thickness did not have any correlation with the annoyance, anger, and satisfaction ratings. It showed a significant correlation only with empathy but the correlation coefficient was quite low ($r = -.20$). Figure 7-4 describes the subjective responses across the three different slab thicknesses (150, 180, and 210 mm). Sites A and B used the same slab thickness (i.e. 150 mm) so the results of the two sites were merged together for this comparison. The lowest annoyance and anger and the highest satisfaction ratings were observed from Site D (Figure 7-3). Similar tendencies were displayed in Figure 7-4, indicating that the annoyance and anger ratings were the lowest and the empathy and satisfaction ratings were the highest from the site with the 180 mm slab. The highest annoyance rating was observed from the sites with the 150 mm slab, while the highest anger rating was from the site with the 210 mm slab. The lowest empathy and satisfaction ratings were from the site with the 210 mm slab. Hence, the increase or decrease in the slab thickness did not correlate with the psychological responses to indoor noise.

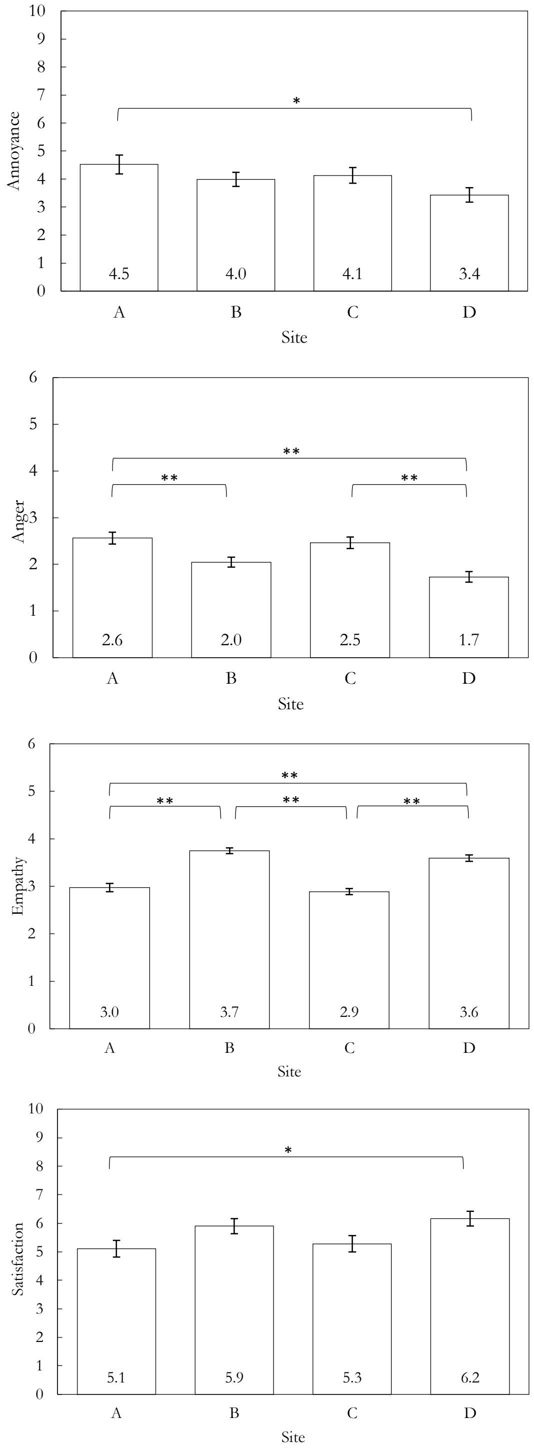


Figure 7-3. Annoyance, anger, empathy, and satisfaction compared between Sites A ~ D. Error bars indicate standard errors (*$p < 0.05$, **$p < 0.01$).

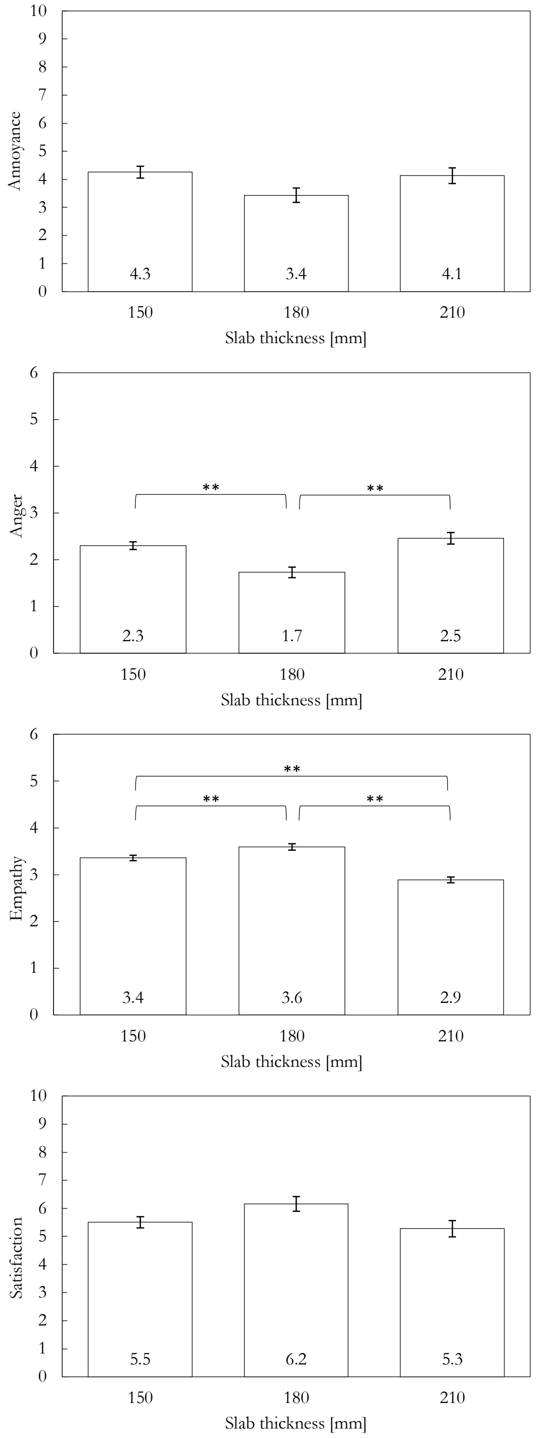


Figure 7-4. Annoyance, anger, empathy, and satisfaction compared between the slab thicknesses of 150, 180, and 210 mm. Error bars indicate standard errors (*$p < 0.05$, **$p < 0.01$).

The participants were classified into two groups with the factor of house ownership (owner and renter) and the factor of self-reported noise sensitivity (low and high). Then the correlations between the subjective responses and house characteristics were examined again separately between the groups. As listed in Table 7-6, the correlation coefficients slightly increased in some groups compared to those in Table 7-5. Although most of the coefficients were still low, it was worth looking into the data more in-depth in order to assess any potential impact of the variables. Specifically, slab thickness and age of the building showed significant correlations with some of the subjective responses. For instance, the slab thickness had the coefficients of -.038 with the annoyance before the data were split into the groups (Table 7-5). However, the correlations became stronger when the noise-sensitivity groups were compared to each other. As shown in Table 7-6(a), the house owners' empathy rating had a negative correlation with the slab thickness but the renters' had a positive correlation. This implies that the house owners living in houses with thicker slabs would be less likely to perceive empathy, whereas the renters living in houses with thicker slabs would be likely to perceive empathy when they heard floor impact noise. Likewise, the house owners' satisfaction had a negative correlation with the slab thickness, while the renters' satisfaction had a positive correlation. In addition, the renter's anger, empathy, and satisfaction had stronger correlations with the age of the building than the owners. It could be viewed that the renters living in older buildings would be more likely to perceive anger and less likely to perceive empathy and satisfaction compared to the house owners. Table 7-6(b) lists the correlation coefficients between the noise-sensitivity groups. Particularly, annoyance and empathy ratings of the high noise-sensitivity group had stronger correlations with the age of the building. It implies that noise-sensitive people living in older buildings would perceive more annoyance and less empathy than less sensitive people.

Table 7-6. Correlations of annoyance, anger, empathy, and satisfaction with the characteristics of the house. The coefficients are shown separately between the groups of (a) house ownership and (b) noise sensitivity ($^{*}p < 0.05$, $^{**}p < 0.01$).

	Annoyance		Anger		Empathy		Satisfaction	
(a) House ownership	Owner	Renter	Owner	Renter	Owner	Renter	Owner	Renter
Slab thickness	.016	-.161	.106	-.177*	-.328**	.079	-.081	.180*
Age of the building	.019	.165	-.005	.332**	.056	-.315**	.013	-.213*
Net floor area of the house	-.036	.041	-.010	.117	-.040	-.161	.027	-.062
	Annoyance		Anger		Empathy		Satisfaction	
(b) Noise sensitivity	Low	High	Low	High	Low	High	Low	High
Slab thickness	-.141*	-.202**	-.156*	-.045	-.349**	-.092	.141*	.047
Age of the building	.115	.482**	.411**	.427**	-.108	-.386**	-.299**	-.284**
Net floor area of the house	-.059	-.001	.007	.116	-.169*	-.098	.026	.021

7.3.3 Characteristics of floor impact noise exposure

The questionnaire asked the participants three questions in regard to the characteristics of the floor impact noise exposure. All the three questions measured nominal or categorical data so the data's correlations could not be tested. As shown in Table 7-3 in which the information about the participants was given, 218 of the participants reported there were one or more children living upstairs, 114 participants reported there was no child living upstairs, and 68 participants answered they did not know if there was any child living upstairs. When the participants' psychological responses to indoor noise were compared between the groups, the results showed that the responses were not affected by whether or not the participants had child(ren) living upstairs. As listed in Table 7-7(a), the most frequent noise source across the sites was children's footstep noise, followed by adults' footstep noise and dropping of objects. In particular, 53 % of the participants from Site B reported children's footstep noise as the major noise source. Furthermore, heavyweight impact sources (children and adults' footstep noises) were more dominant than lightweight impact sources. The responses of the participants who were dominantly exposed to the heavyweight impact noise (n = 254) were compared to those who were dominantly exposed to the lightweight impact noise (n = 146). There was no significant difference between the groups. Table 7-7(b) then presents when the floor impact noise was dominantly heard. Night-time (between 20:00 and 06:00) was the most dominant time for noise exposure, accounting for 54.8 % across the sites. Similarly, the psychological responses to indoor noise were compared between those who were exposed to the noise between 20:00 and 06:00 (n = 219) and the others (n = 181). No significant difference was found between the groups.

Table 7-7. Frequency percentages [%] of (a) major noise source and (b) time of noise exposure.

				Site			
			Whole	A	B	C	D
(a) Major noise source	Heavyweight	Child	38.5	32.0	53.0	37.0	32.0
		Adult	25.0	26.0	18.0	26.0	30.0
	Lightweight	Furniture	12.3	10.0	15.0	12.0	12.0
		Objects	12.5	15.0	10.0	11.0	14.0
		Door	6.3	15.0	0.0	6.0	4.0
		Plumbing	5.5	2.0	4.0	8.0	8.0
(b) Time of noise exposure	06:00 ~ 09:00		28.5	41.0	32.0	18.0	23.0
	09:00 ~ 12:00		4.5	3.0	2.0	7.0	6.0
	12:00 ~ 18:00		3.3	4.0	2.0	4.0	3.0
	18:00 ~ 20:00		9.0	10.0	2.0	16.0	8.0
	20:00 ~ 06:00		54.8	42.0	62.0	55.0	60.0

7.3.4 Outdoor noise

As listed in Table 7-5, none of the outdoor noise characteristics (distance from the road, distance from the railway, and outdoor noise level) showed any significant correlation with floor impact noise annoyance. An additional correlation analysis was conducted in order to examine the data separately for each site because the noise sources and noise levels between the sites were different. Table 7-8 presents the correlation coefficients between the psychological responses to indoor noise and the characteristics of outdoor noise for each site. There is still not much notable correlation found from Sites A, C, and D. Only the responses collected from Site B had statistically significant but weak correlations. For example, annoyance and anger measured from Site B had negative correlations with distance from the road and distance from the railway. It indicates that the participants at Site B who were from the houses closer to the road or railway reported higher annoyance and anger. On the other hand, annoyance and anger had positive correlations with the outdoor noise level. It indicates that the participants who were exposed to higher outdoor noise levels at home reported higher annoyance and anger.

Table 7-8. Correlations of annoyance, anger, empathy, and satisfaction with the characteristics of the outdoor noise. The coefficients are shown separately between the sites (*$p < 0.05$, **$p < 0.01$).

		Characteristics of outdoor noise		
Site	Dependent variables	Distance from the road	Distance from the railway	Outdoor noise level (L_{dn})
Whole	Annoyance	-.036	-.063	.077
	Anger	-.120*	-.102	.113*
	Empathy	.133**	.149**	.016
	Satisfaction	.012	.049	-.033
A	Annoyance	.100	-.136	.170
	Anger	.098	-.191	.206*
	Empathy	-.095	.257**	-.280**
	Satisfaction	-.101	.126	-.195
B	Annoyance	-.257**	-.376**	.300**
	Anger	-.356**	-.429**	.374**
	Empathy	.328**	.394**	-.361**
	Satisfaction	.156	.248*	-.206*
C	Annoyance	.042	.053	-.069
	Anger	.128	-.028	-.057
	Empathy	-.073	.054	.037
	Satisfaction	-.043	-.087	.096
D	Annoyance	.096	.	-.144
	Anger	.017	.	-.064
	Empathy	-.128	.	.149
	Satisfaction	-.164	.	.176

Since there was no railway near to Site D, the cells for the correlations between the distance from the railway and the responses from Site D left as blank in the table.

The annoyance of the outdoor noise had significant correlations with psychological responses to indoor noise (Table 7-5). For instance, annoyance caused by road traffic noise positively correlated with floor impact noise annoyance and anger, while it negatively correlated with empathy and satisfaction. This indicates that the annoyance of outdoor noise had impacts on the subjective response to indoor noise and vice versa. The results of the one-way ANOVA revealed that the road traffic noise annoyance had significant impacts on the floor impact noise annoyance [F (10, 389) = 13.41, $p < 0.01$)], anger [F (10, 389) = 13.24, $p < 0.01$)], empathy [F (10, 389) = 5.78, $p < 0.01$)], and the indoor noise satisfaction [F (10, 389) = 12.78, $p < 0.01$)]. In addition, the railway noise annoyance also had significant impacts on floor impact noise annoyance [F (10, 389) = 18.18, $p < 0.01$)], anger [F (10, 389) = 21.11, $p < 0.01$)], empathy [F (10, 389) = 15.13, $p < 0.01$)], and the indoor noise satisfaction [F (10, 389) = 18.83, $p < 0.01$)]. Further, the total annoyance had significant impacts on floor impact noise annoyance [F (10, 389) = 22.70, $p < 0.01$)], anger [F (10, 389) = 27.83, $p < 0.01$)], empathy [F (10, 389) = 13.93, $p < 0.01$)], and satisfaction [F (10, 389) = 22.33, $p < 0.01$)]. Table 7-9 presents the correlation coefficients between the subjective responses of indoor noise (annoyance, anger, empathy, and satisfaction) and the annoyance of outdoor noise for each site. Among the four sites, the road traffic noise annoyance assessed from Site B had the strongest correlations with the psychological responses to indoor noise. Compared to Site B, relatively weaker correlation coefficients were shown from the other sites. It can be explained by the higher exposure to road traffic noise at Site B compared to the other sites. Although this study did not measure road traffic noise and railway noise separately, the higher exposure to the road traffic noise could be assumed by the participants' self-reported annoyance ratings towards the road traffic noise. The mean road traffic noise annoyance measured at Site B was 5.4 (SD = 2.5) which was the highest among the four sites, followed by Site A (M = 4.3, SD = 2.2), Site C (M = 1.8, SD = 1.3), and Site D (M = 1.1, SD = 1.0). Similar tendencies were shown in the correlations that the railway noise annoyance had. The railway noise annoyance measured from Sites B and C had high correlations with the psychological responses to indoor noise. The higher exposure to the railway noise at Sites B and C could be assumed from the participants' self-reported annoyance ratings towards the railway noise. The mean railway noise annoyance measured at Site C was 6.0 (SD = 2.3) and that of Site B was 5.3 (SD = 2.7) which were higher than that of Site A (M = 2.3, SD = 3.0). Furthermore, the total annoyance of outdoor noise had significant relationships with all the subjective responses of floor impact noise. Specifically, it had positive correlations with the floor impact noise annoyance and anger, and negative correlations with empathy and satisfaction. These results indicate that greater levels of annoyance of outdoor noise led to greater levels of negative responses to indoor noise and vice versa.

Table 7-9. Correlations of annoyance, anger, empathy, and satisfaction with the annoyance of outdoor noise. The coefficients are shown separately between the sites (*p < 0.05, **p < 0.01).

		Annoyance of outdoor noise		
Site	Dependent variables	Road traffic noise annoyance	Railway noise annoyance	Total annoyance
Whole	Annoyance	.434**	.397**	.580**
	Anger	.444**	.473**	.626**
	Empathy	-.269**	-.422**	-.469**
	Satisfaction	-.396**	-.385**	-.559**
A	Annoyance	.537**	.386**	.678**
	Anger	.573**	.425**	.757**
	Empathy	-.592**	-.495**	-.777**
	Satisfaction	-.526**	-.395**	-.692**
B	Annoyance	.738**	.721**	.747**
	Anger	.804**	.807**	.818**
	Empathy	-.768**	-.785**	-.796**
	Satisfaction	-.658**	-.660**	-.680**
C	Annoyance	.401**	.733**	.727**
	Anger	.395**	.772**	.744**
	Empathy	-.388**	-.732**	-.727**
	Satisfaction	-.397**	-.695**	-.700**
D	Annoyance	.430**	.	.545**
	Anger	.470**	.	.589**
	Empathy	-.323**	.	-.487**
	Satisfaction	-.585**	.	-.623**

There is no data shown for Site D because there was no railway nearby the site.

In order to further test the impact of the annoyance of outdoor noise on the psychological responses to indoor noise, the participants were split into two groups according to the levels of annoyance ratings (low and high). First, the participants were separated into two groups according to their road traffic noise annoyance ratings (Figure 7-5). The mean and median road traffic noise annoyance ratings were 3.1 and 2.0, respectively. The median value was used as a cut-off point to divide the participants into two groups. The participants whose annoyance ratings were <= 2.0 were grouped as the low annoyance group (*n* = 209), while those with annoyance ratings above 2.0 were grouped as the high annoyance group (*n* = 191). It was found that the low annoyance group reported significantly lower annoyance and anger perceived towards floor impact noise, and higher empathy and indoor noise satisfaction than the high annoyance group. Second, the participants were split into two groups according to their railway noise annoyance ratings (Figure 7-6). The mean and median railway noise annoyance ratings were 3.4 and 3.0, respectively. The median value was used as a cut-off point to group the participants. The participants whose annoyance ratings were <= 3.0 were grouped as the low annoyance group (*n* = 213) and those with annoyance ratings above 3.0 were grouped as the high annoyance group (*n* = 187). It was observed that the low annoyance group reported significantly lower annoyance and anger perceived towards floor impact noise, and higher empathy and indoor noise satisfaction than the high annoyance group. Third, the responses of the participants were also separated into two groups with their total annoyance ratings (Figure 7-7). The mean and median total annoyance ratings were 4.5 and 4.0, respectively. The median value was used as a cut-off point to group the participants. The participants whose annoyance ratings were <= 4.0 were grouped as the low annoyance group (*n* = 207) and those with annoyance ratings above 4.0 were grouped as the high annoyance group (*n* = 193). The results presented that the low annoyance group reported significantly lower annoyance and anger perceived towards floor impact noise, and higher empathy and indoor noise satisfaction than the high annoyance group.

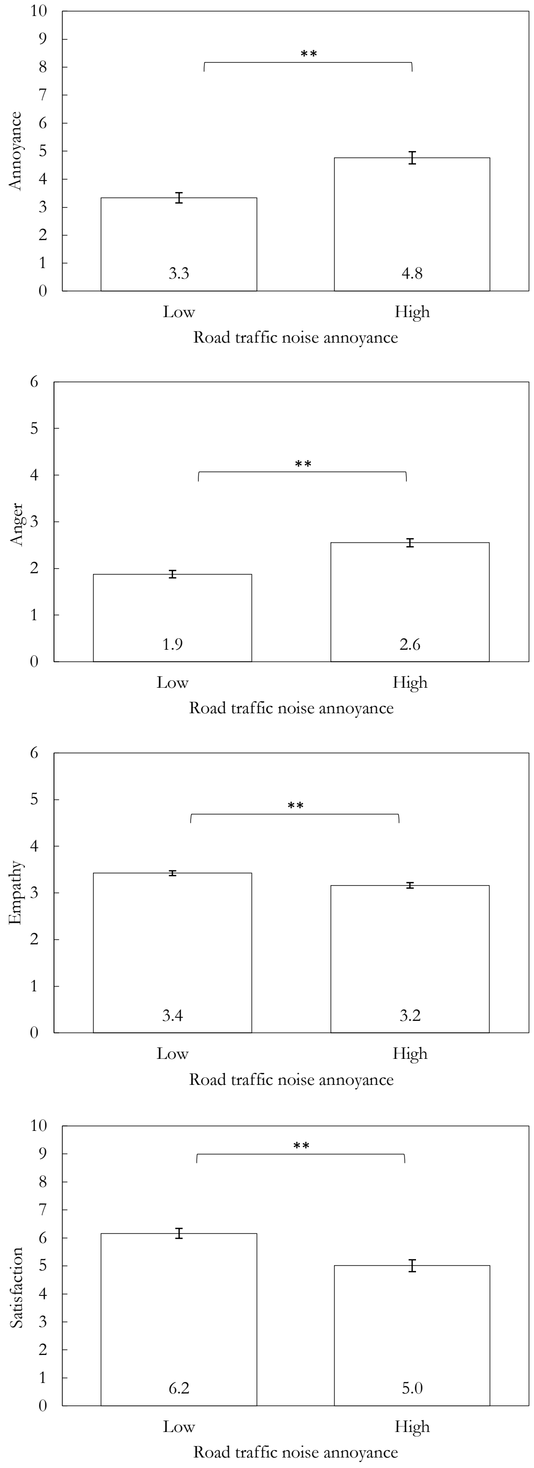


Figure 7-5. Annoyance, anger, empathy, and satisfaction compared between the low and high road traffic noise annoyance groups. Error bars indicate standard errors (*$p < 0.05$, **$p < 0.01$).

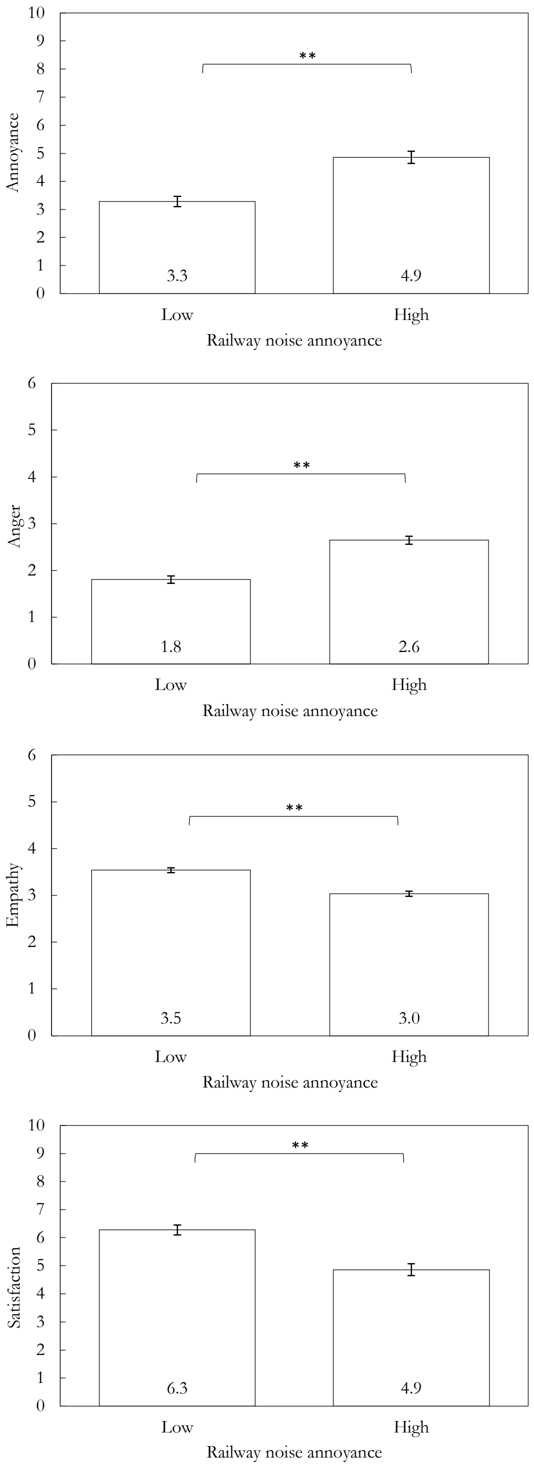


Figure 7-6. Annoyance, anger, empathy, and satisfaction compared between the low and high railway noise annoyance groups. Error bars indicate standard errors (*$p < 0.05$, **$p < 0.01$).

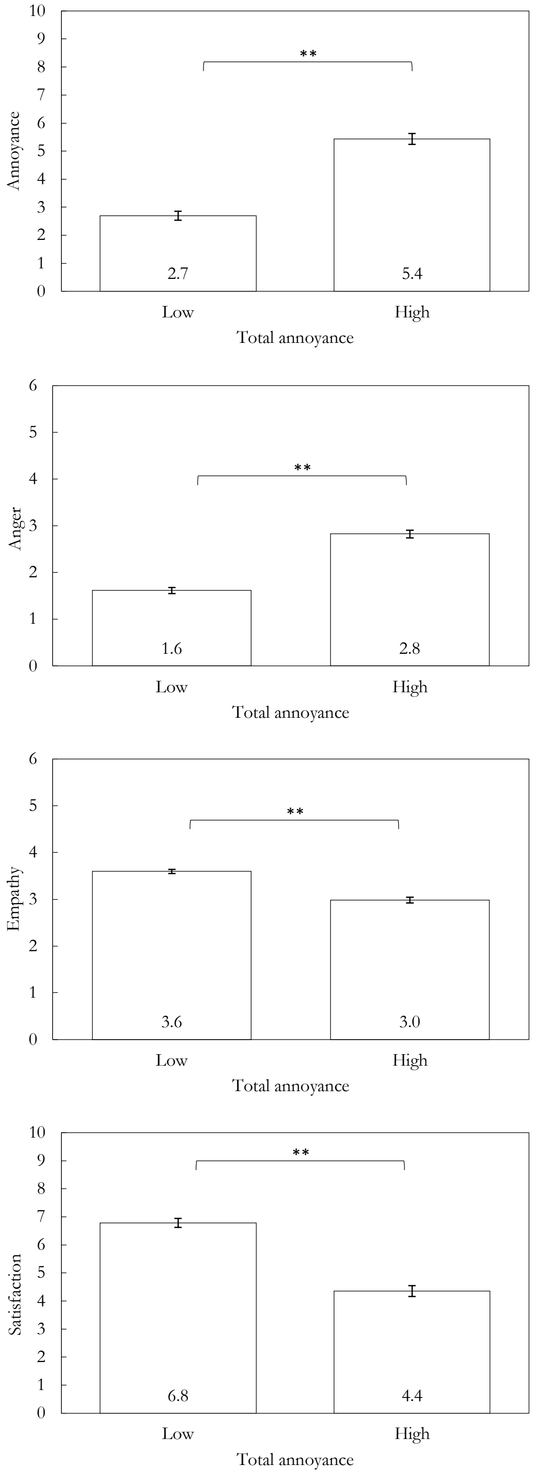


Figure 7-7. Annoyance, anger, empathy, and satisfaction compared between the low and high total annoyance groups. Error bars indicate standard errors (*$p < 0.05$, **$p < 0.01$).

Table 7-10 compares the correlation coefficients between the psychological responses to indoor noise and outdoor noise across the low and high noise-sensitivity groups. Particularly, the annoyance of the high noise-sensitivity group had stronger correlations with the annoyance of outdoor noise. The high noise-sensitivity group showed more significant correlation coefficients between the floor impact noise annoyance and the annoyance of outdoor noise than the less sensitive group. Similar tendencies were identified from other responses to the indoor noise. The correlation coefficient between the anger and the railway noise annoyance for the sensitive group was significantly higher than the less sensitive group. The high noise-sensitivity group's indoor noise satisfaction also had stronger correlation coefficients with the railway noise annoyance than the less sensitive group.

Table 7-10. Correlations of annoyance, anger, empathy, and satisfaction with annoyance of outdoor noises. The coefficients are shown separately between the low and high noise-sensitivity groups (*$p < 0.05$, **$p < 0.01$).

Psychological responses to indoor noise	Noise sensitivity	Annoyance of outdoor noise		
		Road traffic noise annoyance	Railway noise annoyance	Total annoyance
Annoyance	Low	0.121	-0.039	0.118
	High	.359**	.306**	.435**
Anger	Low	.353**	.190**	.380**
	High	.272**	.371**	.426**
Empathy	Low	-0.007	-.246**	-0.099
	High	-0.098	-.277**	-.271**
Satisfaction	Low	-0.125	0.043	-0.136
	High	-.269**	-.311**	-.374**

7.3.5 Multiple linear regressions

Multiple linear regressions were conducted in order to develop models for predicting the subjective responses to indoor noise. The multiple linear regression is an extension of simple regression in which an outcome is predicted by a linear combination of two or more independent variables (Field, 2018). Thus, it was aimed to see how much each factor could predict each of the dependent variables. The dependent variables were the four response to indoor noise. Table 7-11 lists all the dependent variables and independent variables tested in the multiple linear regressions.

Table 7-11. The list of (a) dependent variables and (b) independent variables tested in the multiple linear regressions.

(a) Dependent variables	
Psychological responses to indoor noise	Floor impact noise annoyance Anger evoked by floor impact noise Empathy evoked by floor impact noise Satisfaction with indoor noise environment
(b) Independent variables	
Personal factors	Age Education level Income Length of residency Noise sensitivity
Characteristics of the house	Slab thickness Age of the building Net floor area of the house
Characteristics of outdoor noise	Distance from the road Distance from the railway Outdoor noise level

The following section describes the results of the multiple linear regressions for the dependent variables. In the following tables, β represents the standardised regression coefficient, indicating the strength of the relationship between a tested independent variable presented in a standardised form (Field, 2018). Positive values of β are shown if the independent variable correlated with the dependent variable positively and negative β indicates negative correlations. The tables then present the model summary of the tested regression. In particular, R^2 represents how much the regression model could explain the variance of the dependent variable. The adjusted R^2 is a measure of the loss of predictive power in regression which indicates how much variance in the outcome would be accounted for if the model had been derived from the population from which the sample was taken (Field, 2018).

The result of the multiple linear regression predicting the floor impact noise annoyance as a dependent variable is listed in Table 7-12. As shown in Table 7-12(a), two variables were included in the model with significant coefficients: noise sensitivity and age of the building. In particular, noise sensitivity had a strong and positive coefficient predicting the floor impact noise annoyance. As presented in Table 7-12(b), the regression was statistically significant [F (2, 397) = 484.429, $p < 0.01$] with R^2 of 0.709. Therefore, the regression implies that 70.9 % of the variance of the floor impact noise annoyance could be explained by the two independent variables.

Table 7-12. Results from the multiple linear regressions for predicting the floor impact noise annoyance: (a) the coefficients of the independent variables and (b) the model summary (*$p < 0.05$, **$p < 0.01$).

(a) Coefficients

Independent variables	B	$SE\ B$	β	p
(Constant)	-11.078	.495		.000
Noise sensitivity	.181	.006	.834	.000
Age of the building	.005	.001	.153	.000

(b) Model summary

R	.842
R^2	.709
Adjusted R^2	.708
F	484.429
p	.000

Table 7-13 then shows the result of the multiple linear regression predicting the anger evoked by floor impact noise as a dependent variable. Four variables were included in the model with significant coefficients: noise sensitivity, age of the building, distance from the road, and age of the participant. In particular, noise sensitivity and age of the building had positive coefficients and distance from the road and age of the participant showed negative coefficients predicting the anger. The regression was statistically significant [*F* (4, 395) = 348.680, $p < 0.01$] with R^2 of 0.883. Therefore, the regression implies that 88.3 % of the variance of the anger could be explained by the four independent variables.

Table 7-13. Results from the multiple linear regressions for predicting anger evoked by floor impact noise: (a) the coefficients of the independent variables and (b) the model summary (*$p < 0.05$, **$p < 0.01$).

(a) Coefficients

Independent variables	*B*	*SE B*	*β*	*p*
(Constant)	-3.802	.227		.000
Noise sensitivity	.077	.002	.848	.000
Age of the building	.003	.000	.218	.000
Distance from the road	-.002	.001	-.100	.000
Age	-.008	.003	-.073	.002

(b) Model summary

R	.883
R^2	.779
Adjusted R^2	.777
F	348.680
p	.000

Next, Table 7-14 presents the result of the multiple linear regression predicting the empathy evoked by floor impact noise as a dependent variable. Four variables were included in the model with significant coefficients: noise sensitivity, slab thickness, age of the building, and distance from the railway. The model was significant [*F* (4, 295) = 326.694, $p < 0.01$] and the four variables could explain the variation of empathy 81.6 %. In particular, noise sensitivity, slab thickness, and age of the building had strong negative coefficients explaining the empathy.

Table 7-14. Results from the multiple linear regressions for predicting empathy evoked by floor impact noise: (a) the coefficients of the independent variables and (b) the model summary (*$p < 0.05$, **$p < 0.01$).

(a) Coefficients

Independent variables	*B*	*SE B*	*β*	*p*
(Constant)	12.783	.326		.000
Noise sensitivity	-.047	.002	-.750	.000
Slab thickness	-.025	.001	-.895	.000
Age of the building	-.009	.001	-.801	.000
Distance from the railway	.001	.000	.076	.034

(b) Model summary

R	.903
R^2	.816
Adjusted R^2	.813
F	326.694
p	.000

Last, the result of the multiple linear regression predicting the satisfaction with indoor noise environment as a dependent variable is listed in Table 7-15. Three variables were included in the model with significant coefficients: noise sensitivity, age of the building, and age of the participant. The model was found to be significant [F (3, 396) = 411.459, $p < 0.01$] and could explain the variation of satisfaction 75.7 %. Noise sensitivity particularly had a strong and negative coefficient explaining the satisfaction with indoor noise environment.

Table 7-15. Results from the multiple linear regressions for predicting satisfaction with indoor noise environment: (a) the coefficients of the independent variables and (b) the model summary (*$p < 0.05$, **$p < 0.01$).

(a) Coefficients

Independent variables	*B*	*SE B*	*β*	*p*
(Constant)	19.956	.538		.000
Noise sensitivity	-.181	.005	-.859	.000
Age of the building	-.004	.001	-.136	.000
Age	.016	.007	.062	.014

(b) Model summary

R	.870
R^2	.757
Adjusted R^2	.755
F	411.459
p	.000

7.3.6 Health consequences

The impacts of the psychological responses to indoor noise on adverse health consequences were assessed. Self-reported quality of life and objectively measured blood pressure were introduced as health consequences. The quality of life was evaluated with two components: physical health-related quality of life ('physical health quality') and mental health-related quality of life ('mental health quality'). The data of blood pressure also consisted of two components: diastolic and systolic blood pressure. First, the results of the one-way ANOVA revealed that the effects of the floor impact noise annoyance on the mental health quality [F (10, 389) = 3.32, $p < 0.01$)], diastolic blood pressure [F (10, 389) = 51.07, $p < 0.01$)], and systolic blood pressure [F (10, 389) = 51.90, $p < 0.01$)] were significant. The participants were then grouped into low and high floor impact noise annoyance groups. Both mean and median annoyance ratings were 4.0 and it was used as a cut-off point to group the participants. As illustrated in Figure 7-8, the low floor impact noise annoyance group (n = 196) reported significantly higher physical and mental health qualities than the high annoyance group ($n = 204$). Moreover, significantly lower diastolic and systolic blood pressures were measured from the low annoyance group. Second, anger perceived towards floor impact noise had significant impacts on the physical health quality [F (25, 374) = 1.68, $p < 0.05$)], mental health quality [F (25, 374) = 1.73, $p < 0.05$)], diastolic blood pressure [F (25, 374) = 21.56, $p < 0.01$)], and systolic blood pressure [F (25, 374) = 26.09, $p < 0.01$)]. The participants were grouped into low and high anger groups (Figure 7-9). The mean and median anger ratings were 2.2 and 1.9, respectively. The median value was used as a cut-off point to group the participants. The low anger group ($n = 200$) reported significantly higher physical and mental health qualities than the high anger group ($n = 200$). Significantly lower diastolic and systolic blood pressures were measured from the low anger group. Third, empathy had significant impacts on the physical health quality [F (24, 375) = 1.72, $p < 0.05$)], mental health quality [F (24, 375) = 2.40, $p < 0.01$)], diastolic blood pressure [F (24, 375) = 10.15, $p < 0.01$)], and systolic blood pressure [F (24, 375) = 10.87, $p < 0.01$)]. As Figure 7-10 presents, the participants were grouped into low and high empathy groups. Both mean and median empathy ratings were 3.3 and it was used as a cut-off point. The low empathy group ($n = 179$) reported significantly higher physical and mental health qualities than the high empathy group ($n = 221$). The low empathy group had significantly lower diastolic and systolic blood pressure. Fourth, satisfaction with indoor noise environment had significant impacts on the physical health quality [F (10, 389) = 2.04, $p < 0.05$)], mental health quality [F (10, 389) = 4.05, $p < 0.01$)], diastolic blood pressure [F (10, 389) = 44.89, $p < 0.01$)], and systolic blood pressure [F (10, 389) = 44.78, $p < 0.01$)]. The participants were grouped into low and high satisfaction groups. The mean and median anger ratings were 5.6 and 6.0, respectively and the median value was used as a cut-off point. The low satisfaction group ($n = 201$) reported significantly lower physical and mental health qualities than the high satisfaction group ($n = 199$) as shown in Figure 7-11. Higher diastolic and systolic blood pressures were measured from the low satisfaction group and the difference between the groups was statistically significant.

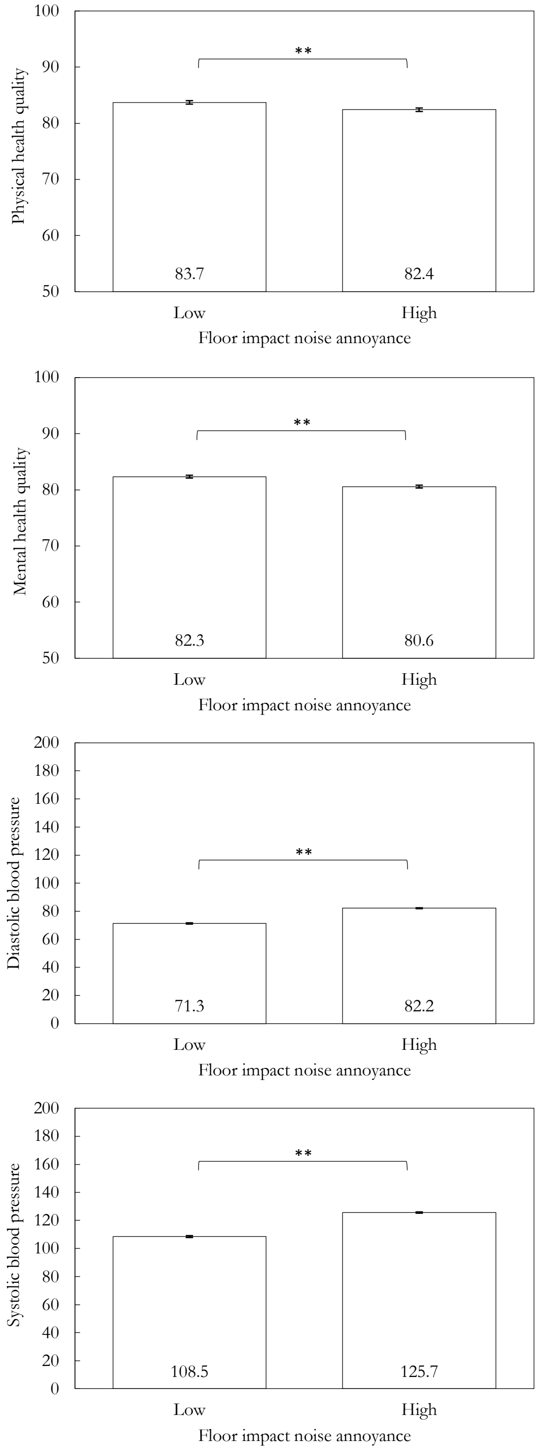


Figure 7-8. Physical and mental health-related quality of life and blood pressure (diastolic and systolic) compared between the low and high floor impact noise annoyance groups. Error bars indicate standard errors (*$p < 0.05$, **$p < 0.01$).

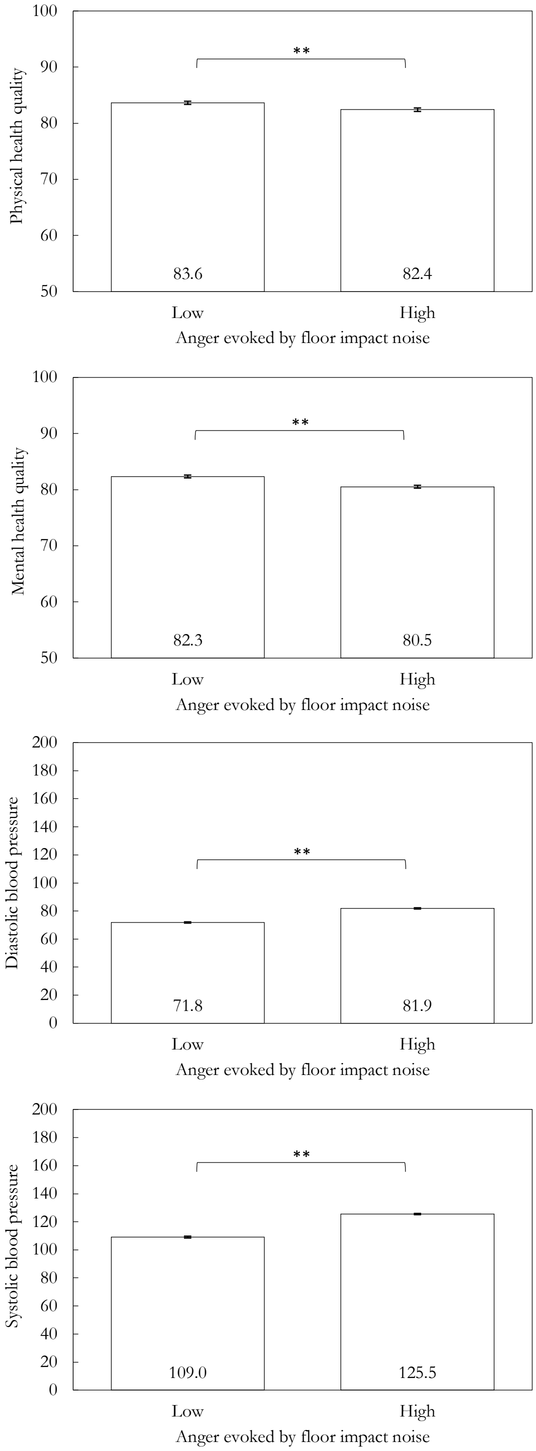


Figure 7-9. Physical and mental health-related quality of life and blood pressure (diastolic and systolic) compared between the low and high anger groups. Error bars indicate standard errors (*$p < 0.05$, **$p < 0.01$).

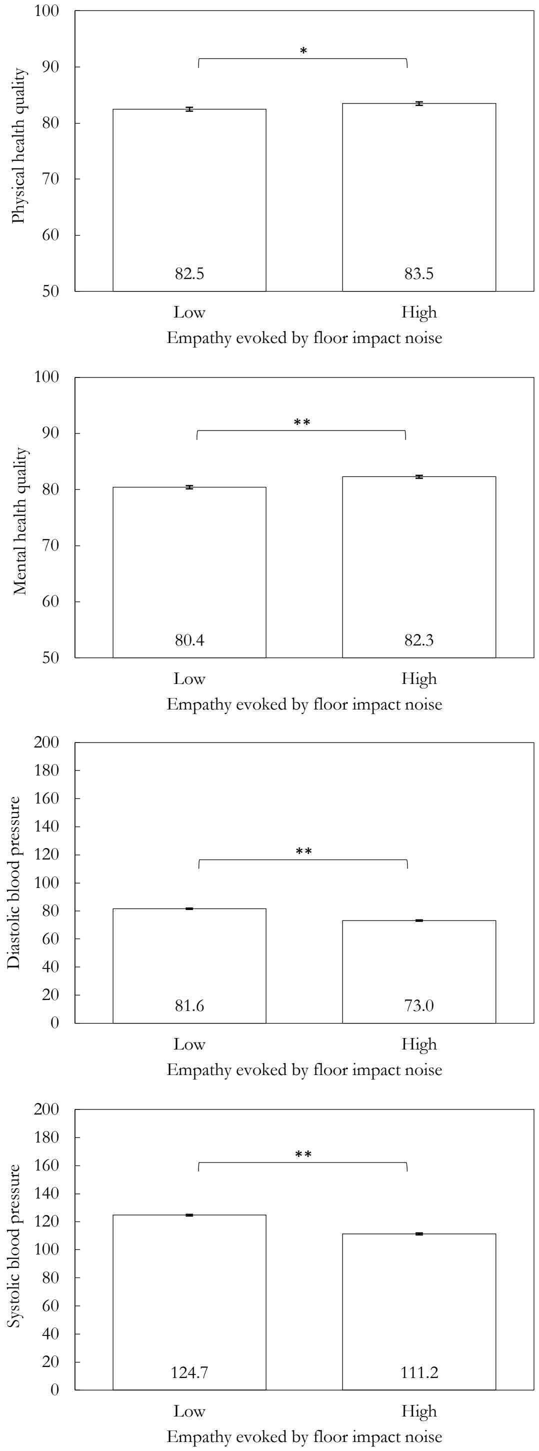


Figure 7-10. Physical and mental health-related quality of life and blood pressure (diastolic and systolic) compared between the low and high empathy groups. Error bars indicate standard errors (*$p < 0.05$, **$p < 0.01$).

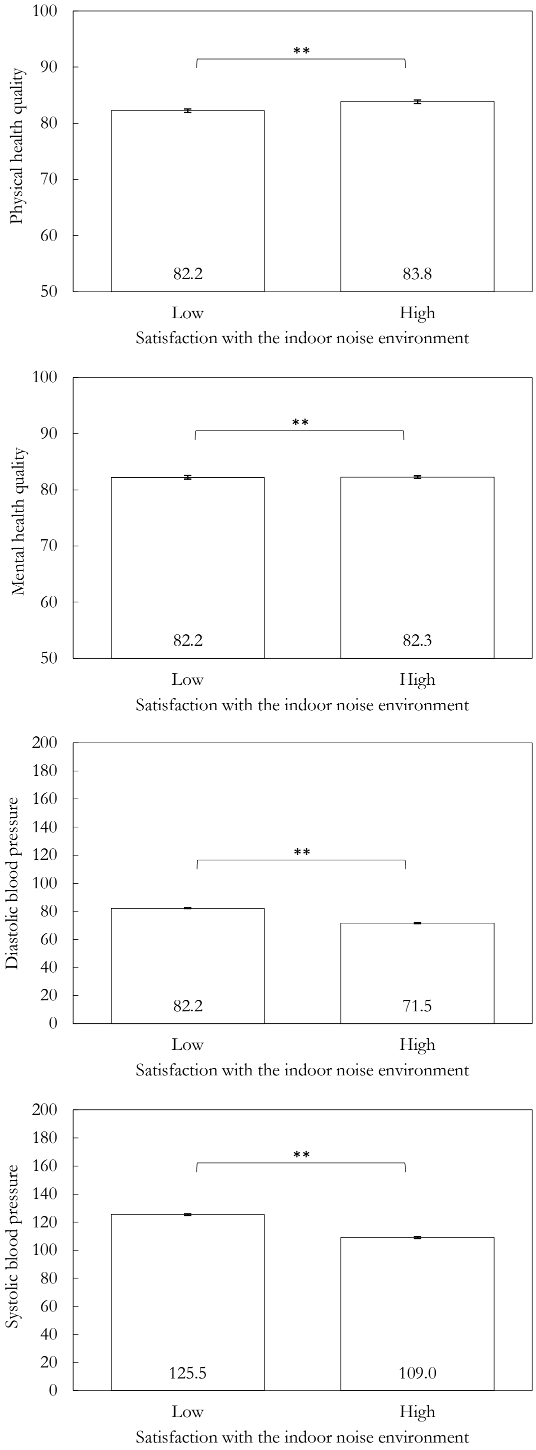


Figure 7-11. Physical and mental health-related quality of life and blood pressure (diastolic and systolic) compared between the low and high indoor noise satisfaction groups. Error bars indicate standard errors (*$p < 0.05$, **$p < 0.01$).

7.4 Discussion

This study tested and validated the findings from previous studies in Chapters 3 ~ 6. First, the study in Chapter 3 reported that the major sources of floor impact noise were human (adults and children) footsteps, dropping of small objects, and movement of furniture from the acoustic measurements. This study confirmed that the adults' and children's footstep noises were the most dominant noise sources followed by scraping of furniture and dropping of objects. In addition, the study in Chapter 3 discovered that the slab thickness did not correlate with the noise level. Although the current study did not conduct any indoor noise measurement, this study could partially support the previous suggestion, representing that the floor impact noise annoyance was not significantly correlated with the slab thickness. Second, Chapters 5 and 6 addressed that the self-reported noise sensitivity had significant impacts on both psychological and physiological responses to floor impact noise stimuli in laboratory settings. The current study validated this finding, showing the self-reported noise sensitivity had significant impacts on all the psychological responses to floor impact noise (annoyance, anger, and empathy) and the satisfaction with indoor noise environment in the field study. It was not reported in Subchapter 7.3 how noise sensitivity related to the blood pressure because it was not what the research questions of this study asked about. The mean diastolic blood pressure of the low noise-sensitivity group was 71.6 (*SD* = 6.2) and that of the high noise-sensitivity group was 82.3 (*SD* = 4.8). The mean systolic blood pressure of the low noise-sensitivity group was 109.8 (*SD* = 10.6) and that of the high noise-sensitivity group was 125.0 (*SD* = 7.2). In addition, there were significant differences between the two noise-sensitivity groups' blood pressures. Hence, this study supported and extended the previous findings in Chapters 4 ~ 6 by revealing the impact of self-reported noise sensitivity on blood pressure. Third, Chapters 4 and 5 addressed the significant changes in the physiological responses during the floor impact noise exposures in the laboratory settings. Instead of the heart rate, electrodermal activity, and respiration rate, the current study measured blood pressure because it was the feasible measure for the field study. In addition to the blood pressure measurement, this study also measured the self-reported quality of life in order to assess subjective health conditions of each participant. The results from this field study were in line with the findings in the previous studies as it was found that those who reported lower negative responses to floor impact noise (annoyance and anger) had lower blood pressure and better quality of life.

7.4.1 Outdoor noise levels

It was assumed that the outdoor noise would mask the indoor noise and thereby have impacts on the psychological responses to indoor noise. In order to test this, outdoor noise levels were measured and the annoyance ratings of outdoor noise were assessed using the questionnaire. The outdoor noise level did not have any relationship with the psychological responses to indoor noise. However, the annoyance of outdoor noises (e.g. road traffic noise annoyance) had significant positive correlations with the negative responses to floor impact noise (annoyance and anger). Those who reported higher annoyance of the outdoor noise consistently reported higher negative responses to the indoor noise. Therefore, there was no masking effect of the outdoor noise seen in this study. On the other hand, the self-reported noise sensitivity might have impacts on the outdoor noise annoyance because it was found that those with higher noise sensitivity showed higher correlations between the psychological responses to indoor noise and the annoyance of outdoor noise. Additional independent samples *t*-tests were carried out and the results showed that the low noise-sensitivity group reported significantly lower road traffic noise annoyance ($M = 2.3$, $SD = 1.9$) than the high noise-sensitivity group ($M = 4.0$, $SD = 2.8$). The low noise-sensitivity group also reported significantly lower railway noise annoyance ($M = 2.2$, $SD = 2.3$) than the high noise-sensitivity group ($M = 4.7$, $SD = 1.7$). Further, the total annoyance was significantly lower from the low noise-sensitivity group ($M = 3.3$, $SD = 1.7$) than the high noise-sensitivity group ($M = 5.7$, $SD = 2.1$). These findings imply that the individual's self-reported noise sensitivity played an important role when it comes to the perceptions of noise. Furthermore, those who reported higher annoyance or anger to floor impact noise had higher blood pressure and reported worse quality of life. It can be assumed that various factors including indoor and outdoor noise exposures, and the noise sensitivity might integrate altogether and affect the blood pressure and the self-reported quality of life.

7.4.2 Indoor noise levels

Previous field studies on indoor noise mainly focused on sound insulation performance (Huang, 2014; Ljunggren et al., 2014; Baek et al., 2015; Ljunggren et al., 2017; Yeon et al., 2017). Therefore, they either did not concern real noise sources (Ljunggren et al., 2014; Ljunggren et al., 2017) or did not evaluate the subjective responses to the noise (Huang, 2014; Baek et al., 2015; Yeon et al., 2017). Ljunggren and his colleagues measured the sound insulation performances of floors using standard sources (e.g. tapping machine and impact ball) in different types of buildings (Ljunggren et al., 2014; Ljunggren et al., 2017). They also collected the occupants' subjective responses to the noise but did not measure real noise sources such as human footsteps coming from upstairs. On the other hand, the present study paid attention to the residents' subjective response to real indoor noises. Moreover, this study mainly focused on the slab thickness in order to test previous findings (Kimura, 1996; Jeon et al., 2006b; Huang, 2014; Baek et al., 2015). This study has revealed that increased slab thickness cannot guarantee better acoustic comfort because all the residents are exposed to different levels of noises according to their upstairs neighbours' activities and behaviour as suggested in Chapter 3. Since the indoor noise levels were not measured in this study, it is inevitable that there is a need for performing research to show the relationship between the indoor noise level and the residents' subjective reaction to noise.

As just mentioned, the indoor noise measurement was not conducted in this study. This study rather adopted the slab thickness as one of the independent variables assuming that indoor noise level decreases as slab thickness increases (Kimura, 1996; Jeon et al., 2006b; Huang, 2014). The study examined whether the slab thickness affected the subjective responses to floor impact noise. There was no strong trend between different the slab thicknesses and the subjective ratings. The participants living in buildings with the thinnest slab (150 mm) gave the highest annoyance rating, followed by those in buildings with the 210 and 180 mm slabs. In addition, the participants in buildings with the 210 mm slab expressed the highest anger, while the empathy rating of the participants in buildings with the 180 mm slab was greater than those in buildings with the 150 mm slab. These findings are not consistent with the previous suggestions made in laboratory studies in which the thicker slab thickness leads to the lower noise levels (Kimura, 1996; Jeon et al., 2006b), and that the lower the noise levels result in lower annoyance ratings (findings from Chapters 4 and 5). Instead, the present study yielded further evidence supporting the findings of the prior field research (e.g. Yeon et al., 2017). As reported earlier in Chapter 3, an increase in slab thickness cannot guarantee better acoustic comfort with the lower noise levels or the fewer noise events in real-life since the occurrence of neighbouring noise including floor impact noise is mainly affected by the neighbour's behaviours and activities. Yeon et al. (2017) also reported that slab thickness had a minimal correlation with noise levels from a real impact source. Moreover, the results from the multiple linear regression analyses confirmed that the subjective responses to floor impact noise can be explained not just by the acoustic factors such as sound insulation performance from the slab thickness, but also by different non-acoustic factors (Park et al., 2016a). Furthermore, impact sound insulation performance is affected by various factors such as dynamic properties of resilient isolator and floor areas. In the present study, the resilient isolators of the Sites C and D had much lower dynamic stiffness compared to those of the Sites A and B which were built before the introduction of domestic guideline of sound insulation performance. In addition, previous studies (e.g. Lee, 2004) reported that the heavyweight impact sound insulation performances varied across floor areas for apartments with same floor structure and resilient material. Therefore, some particular features of each site and the participants need to be compared with one another in order to seek out any potential factors affecting the subjective ratings. Moreover, experimental and numerical approaches (e.g. Hirakawa and Hopkins, 2018) could be used to predict the heavyweight impact sound insulation performances and to examine the links between objective characteristics and subjective responses.

7.4.3 Financial investment

One of the unexpected findings in this study was that the participants from Site C, which used the thickest slabs (210 mm), reported higher negative responses (annoyance and anger) than those from Sites B and D which used the thinner slabs (150 and 180 mm, respectively). This result implies that other socio-demographic variables might have affected the subjective responses. It has been known that house owners are concerned about local noise and expect future improvement more than renters. This is mainly because house owners financially invest more into the property than renters (Schreckenberg, 2008). House ownership is a long-term investment, so it is quite clear that investors are interested in maintaining and increasing the value of their investment (Friedrichs and Blasius, 2009). In this study, most of the participants from Sites A, B, and C were house owners, whereas all the participants from Site D were renters. As the results showed, house owners reported significantly higher annoyance and anger than renters. Given that most of the renters in this study were from one site (Site D), there is still a remaining question whether the renters in this study could actually be representative. Thus, further investigation is needed into this factor by recruiting the samples with wider ranges of factors. Given that the net floor area of residence is the biggest in Site C, the participants in Sites C must have a greater financial investment than those in the other sites. Therefore, residents who paid more for the properties might expect better acoustic comfort, more concern, and were more annoyed by noise in their dwellings (Fields, 1992; Miedema and Vos, 1999). Since this study did not ask the participants how much money they invested in their properties (e.g. house price and mortgage), future research could examine the impacts of the financial investment on the subjective responses. Given that this study found that noise sensitivity had significant impacts on the responses, future research could also assess how financial investment associates with noise sensitivity.

7.4.4 Sense of community and site layout

Having conducted the study at the four different sites, there was a possibility that the layout of the sites might have affected the residents' sense of community (Chavis et al., 1986; Seik, 2001). Contrary to other sites, each building in Site C was surrounded by fences with separated gates; in addition, 4 m trees were planted along the fences. This layout may improve the residents' security and privacy. However, there might be a lack of social cohesion or sense of community, and consequently, the participants from Site C where the thickest slabs were used might have reported high annoyance and anger ratings. However, this is not in agreement with the previous findings, which reported that neighbours with more privacy complained less about one another (Engle Merry, 1993) and that a sense of community increases when people feel less crowded and have more privacy (Brodsky et al., 1999; Wood et al., 2010). The disagreement between this study and the previous research (Engle Merry, 1993; Brodsky et al., 1999; Wood et al., 2010) might be due to the different housing types. Contrary to the previous studies (Engle Merry, 1993; Brodsky et al., 1999; Wood et al., 2010), this study focused on high-rise multi-family housings. The participants from Site A consistently gave higher annoyance and anger ratings and lower empathy ratings than those from Site B. The differences between Sites A and B can be explained in term of site layout. The playgrounds and relaxing areas (e.g. benches) of Site B were located in the middle of the site which was surrounded by the residential buildings. Thus, the participants in Site B might be easily mixed and encounter each other in this space. This design also might produce a high degree of enclosure and help to create places where people feel safe and comfortable. On the other hand, the communal areas of Site A were spread across a huge site, so it was less likely to expect social cohesion among the residents of the site. Besides, Site A had a much greater number of residences and buildings than Site B. The floor impact noise issue concerned only upstairs neighbours rather than considering neighbours in different buildings. However, the floor impact noise issue should be understood as a community issue as a whole. It is because a lack of social cohesion in the community produces a negative or less positive attitude towards neighbours in general, which could affect the responses to noise from upstairs after all (Park et al., 2016a; Park et al., 2016b; findings from Chapter 6). Given that annoyance response is closely associated with less social cohesion (Meegan and Mitchell, 2001; Dzhambov et al., 2017), Lee and Park (2015) also suggested the potential impact of the sense of community on noise annoyance. The study focused on residents living in apartments, which was part of a Korean Government-funded project aiming to promote a sense of community. The study revealed that the residents in these apartments reported lower annoyance than those in other apartments which did not participate in the project (Lee and Park, 2015). This finding provided evidence that the improvement of social cohesion could reduce the residents' complaints about neighbouring noise and annoyance. It was also reported that empathy towards their upstairs neighbours would reduce the negative responses to neighbouring noise (Park et al., 2016a; findings from Chapter 6). Empathy associates with social cohesion. For instance, Davies and Herbert (1993) earlier noted that the function of empathy or a sense of belonging is related to social cohesion or integration. Therefore, it would be logical to expect that improvements in the social cohesion with their neighbours would reduce potential conflict between neighbours regarding many problems, including the floor impact noise issue.

7.5 Summary

This study aimed to fulfil an existing need, as there was a lack of field research on subjective responses to floor impact noise (e.g. footstep noise of upstairs neighbours). Four sites with different slab thicknesses were recruited for on-site evaluations. One hundred residents from each site took part in the study, so a total of 400 responses were collected and analysed. A questionnaire was used to evaluate the residents' annoyance, anger, and empathy perceived by floor impact noise, satisfaction with indoor noise environment, and self-reported quality of life. In addition, the questionnaire contained question items regarding demographic characteristics, self-reported noise sensitivity, characteristics of the floor impact noise (e.g. major noise source), and annoyance of outdoor noise sources. Along with the questionnaire, blood pressure of the participants was measured. Furthermore, outdoor noise levels were measured at each site in order to investigate the effect of the outdoor level on the participants' responses. The results showed that self-reported noise sensitivity and house ownership had significant impacts on the responses. There was no notable correlation between the slab thickness and the responses. This finding indicates that an increase in slab thickness was not enough to resolve the conflict of floor impact noise between neighbours. The characteristics of the floor impact noise (e.g. major noise source) also did not have any significant impact on the responses. The negative annoyance of outdoor noise (e.g. railway noise annoyance) had positive correlations with the negative responses to floor impact noise (e.g. annoyance and anger) which implied that the participants tended to rate both indoor and outdoor noise similarly. The negative responses to indoor noise had adverse effects on the self-reported quality of life and blood pressure. Table 7-16 presents the summary of the major findings of this study with the research question of the study.

Table 7-16. The research question and the findings of this study.

Research questions	Findings
▪ What factors have effects on the responses to floor impact noise?	▪ House ownership and noise sensitivity influenced the psychological responses to indoor noise. Other personal factors did not show any relationship with the responses. ▪ Characteristics of the house (e.g. slab thickness) and floor impact noise exposure (e.g. major noise source) did not show any relationship with the psychological responses. ▪ The characteristics of the outdoor noise (e.g. outdoor noise levels) did not show any relationship with the psychological responses to indoor noise. However, the outdoor noise annoyance had positive correlations with the psychological responses to indoor noise. Thus, outdoor noise did not have any masking effect on the psychological responses to indoor noise. Moreover, noise sensitive participants reported higher annoyance of both indoor and outdoor noises.

8 Attitudes to neighbours and coping with their noise: A qualitative study

8.1 Introduction

Utilising the research methods of grounded theory, the author's previous work developed a conceptual model to explain how residents in multi-family housing perceive and react to floor impact noise (Park, 2015b). The conceptual model contained the following concepts: noise exposure, disturbance, annoyance, coping, health risks, and intervening conditions. The studies in Chapters 3 ~ 7 could test and validate some of the concepts such as annoyance, health risks, and noise sensitivity which was one of the intervening conditions. However, another intervening condition suggested in the model, attitude towards neighbours, and coping still remain unclear when it comes to their impacts on residents' responses to the noise. Utilising the grounded theory methods again this time, this study particularly focused on investigating these factors. It aimed to investigate the relationship between how residents cope with neighbour noise and their attitudes towards the neighbours. Residents in multi-family housing are dominantly exposed to neighbour noise. Similar to other environmental noises, there are a number of acoustic and non-acoustic variables affecting subjective responses to the noise. This paper particularly focuses on the relationship between the way residents cope with neighbour noise and their attitudes to the neighbours who caused the noise. Utilising grounded theory methods, in-depth interviews with 57 residents in multi-family housing were carried out. The study examined how residents developed different attitudes towards their neighbours, what factors had influences on the attitudes, and how the different attitudes led to different copings. The study was conducted based on the following research question and objectives as shown in Table 8-1.

Table 8-1. The research question and objectives of the present qualitative study

Research questions	Objectives
▪ What factors have effects on the responses to floor impact noise?	▪ To investigate how different attitudes result in different copings. ▪ To investigate factors which have impacts on the individual's attitude.

8.2 Methods

8.2.1 Data collection and analysis with grounded theory methods

The whole procedures of data collection and analysis were conducted based on grounded theory methods (Glaser and Strauss, 1967). While the data were being collected, the data were simultaneously synthesised and conceptualised, and again interacted with the emerging ideas. The interview transcripts were manually coded line by line using the interviewee's own words and immediate expressions. The codes were developed into conceptualised ideas, which were then grouped with descriptive labels, namely concepts. As the grounded theory methods conduct the data analysis by the conceptualisation of data, concepts are the basic building blocks in grounded theory construction (Pandit, 1996). The emerged concepts were compared with the raw data (e.g. transcripts) and memos again several times. Since the data collection and analysis phases were carried out simultaneously, the emerging analyses not only shaped the idea but also were refined by the further data collection. The concepts were then developed into a model showing the paradigm among them (Corbin and Strauss, 2008). This study also focused on identifying various conditions. Conditions refer to a wide range of factors that cause the phenomenon, influence the causal impact, or create a set of circumstances in which the individual responds through actions and interactions (Corbin and Strauss, 2008).

8.2.2 Participants

This study carried out in-depth interviews with residents living in multi-family residential buildings in South Korea. Duration of the interviews ranged from 1.5 to 3 hours. In the procedure of studying, conceptualising, and understanding the relationship between coping and attitude, there were various conditions emerged. New participants were recruited and interviewed until the author was confident that saturation was attained and no more ideas were emerging (Corbin and Strauss, 2008). The interviews were carried out with a total of 57 participants. None of the participants had hearing disabilities. As Table 8-2 lists, age of the interviewees ranged from 24 to 65 (M = 39.4; SD = 7.5). Twenty-six of them were males. Twenty-nine interviewees had lived with one or more children in their homes. More than half of them (31 interviewees) had made complaints regarding their current neighbours' noise. Each interviewee's information can be found in Appendix 6.

Table 8-2. Information about the interviewees (N = 57).

		Number	%
Age	20s	3	5.3
	30s	26	45.6
	40s	25	43.9
	50s	1	1.8
	60s	2	3.5
Gender	Male	26	45.6
	Female	31	54.4
Child(ren) at home	Yes	29	50.9
	No	28	49.1
House ownership	Owned	41	71.9
	Rented	16	28.1

		Number	%
Length of residency [year]	Less than 1	7	12.3
	1 ~ 2	11	19.3
	2 ~ 5	19	33.3
	5 ~ 10	10	17.5
	10 ~ 15	5	8.8
	More than 15	5	8.8
Noise complaint experience	Yes	31	54.4
	No	26	45.6

8.2.3 Procedure

The interviews were carried out individually with each interviewee. Before obtaining informed consent, the author explained the purpose of the study, answered the interviewee's questions, and asked permission to audio-record the interview. Interviews were audio-recorded, transcribed verbatim, translated into English, and then checked for data accuracy. The interviewee was assured of complete anonymity, and all transcripts were pseudonymised. Each interviewee received KRW 30,000 (approximately GBP 20) gift card for the participation.

8.3 Results and discussion

8.3.1 From noise exposure to consequence

The experience of neighbour noise exposure can also be explained using several key concepts which closely interact with each other. Figure 8-1 describes the connections between the key concepts obtained from the interviews based on the existing stress theory as suggested by Lazarus and Folkman (1984). The key concepts are (1) attitude towards their neighbours, (2) conditions, (3) annoyance, (4) coping, and (5) consequence. Previously, the attitude towards neighbours was suggested as being one of the intervening conditions (Park et al., 2016a). However, this study described them separately in order to focus on attitude. Conditions and attitude have a reciprocal relationship, and they also have reciprocal connections with annoyance and coping. Annoyance is one of the major responses to floor impact noise as suggested in the previous studies (Chapters 3 ~ 7) which strongly correlates with various emotional changes (Chapters 6 and 7). Annoyance results in coping which includes cognitive and behavioural coping strategies (Habarth et al., 2009). Cognitive coping is an indirect strategy, whereas behavioural coping is a direct problem-solving behaviour (Folkman and Lazarus, 1988). The behavioural coping strategy consists of avoidant (e.g. going out to avoid noise exposure) and vigilant coping, such as making a phone call to the neighbours (Park et al., 2016a). Coping leads to consequence, which indicates the different outcomes of the problem (e.g. not changed or solved). As described in Figure 8-1, the consequence could influence the attitude towards neighbours, other conditions, annoyance, and coping. This paper particularly focuses on discussing the inter-relationships between three key concepts: attitude towards the neighbours, conditions, and coping.

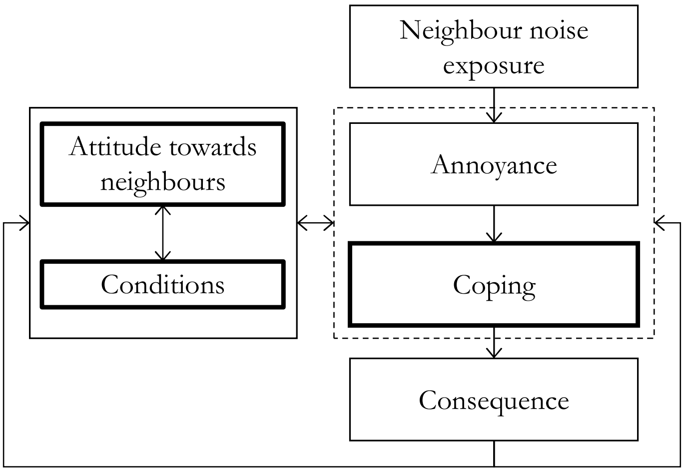


Figure 8-1. Relationships between the key concepts describing the experience of exposure to neighbour noise. The concepts which this study has focused on are marked with thicker borders.

8.3.2 How residents feel about their neighbours

The interviewees expressed what they think about their neighbours and their reactions involved verbal expressions, coping strategies, and the tone of their voices or facial expressions. The interviewees reported a wide range of reaction (affect) towards their neighbours, depending on their experience and relationship with their neighbours. Some of their affect was positive, whereas others had negative feelings about their neighbours. It was also observed that the affect towards the neighbours varied in terms of its intensity. Therefore, it was assumed that the attitude towards one's neighbours can be explained by the affect towards their neighbours and the intensity. Sample quotes from the interviewees in Table 8-3 show both positive affect and negative affect with their intensity. First, the table shows positive affect from three interviewees (#7, #44, and #34). Interviewee #7 expressed strong positive affect by saying that she was lucky to have such "good friends". Interviewee #34 also expressed positive affect towards her neighbours, but the intensity was quite weak in comparison to the expression of Interviewee #7. She said that she did "not know much about" her neighbours, indicating a weak relationship with them. Interviewee #44's positive affect can be positioned between that of Interviewee #7 and Interviewee #34 in terms of intensity. On the other hand, Interviewees #46, #50, and #32 expressed negative affect towards their neighbours. Interviewee #46 strongly expressed her negative views on her neighbours. She did "not want to see" her neighbours anymore and hoped that they would move out. She shared her thoughts about the neighbours in an angry voice throughout the interview. Interviewee #32 also reported negative affect towards their neighbours, but the intensity was weaker than that of Interviewee #46. Full quotes from the individual interviewees can be found in Appendix 6.

Table 8-3. Sample quotes from the interviewees showing their affect towards their neighbours.

No.	Quote	Affect	Intensity
7	"I'm lucky to have such good friends as my neighbours."	Positive	Strong
44	"They are quite nice people. I am totally fine with them."		~
34	"I'm fine with them ... I don't know much about them."		Weak
46	"I don't want to see them. I really hope they'll move out."	Negative	Strong
50	"He says they [neighbours] are very rude."		~
32	"I sometimes don't understand them."		Weak

The diagram in Figure 8-2 was developed based on the interviewees' affect towards their neighbours and its intensity. Figure 8-2 illustrates that residents may consider their neighbours as an enemy, friend, or stranger/acquaintance depending on the strength of the positive or negative affect towards the neighbours. The affect towards the neighbours can be located between negative and positive, while the intensity ranges from weak to strong. Neighbours can be strangers or acquaintances if the intensity of the affect is not strong. Strangers or acquaintances can be felt as negative, positive, or somewhere in between based on various conditions. The neighbours can be seen as an enemy if the residents feel negative affect with strong intensity. On the other hand, residents can see their neighbours as friends when the affect is positive with strong intensity.

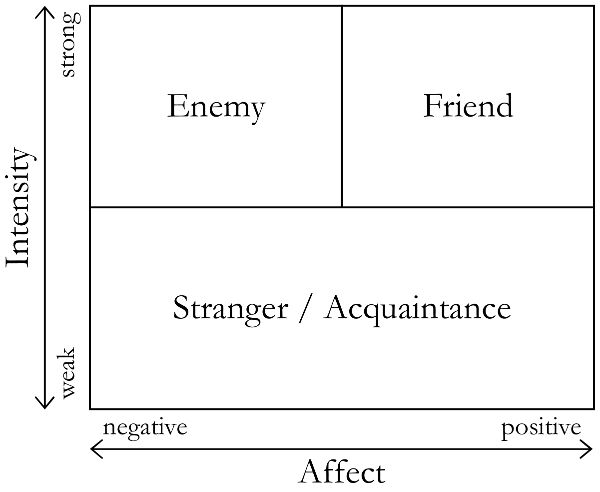


Figure 8-2. Residents' attitudes towards their neighbours in terms of affect and its intensity.

8.3.3 How the attitude is formed

> "I am very sensitive to noise ... I can't concentrate if somebody starts talking or whispering to someone at the library ... but I'm fine with the people upstairs. I can hear their footsteps but it doesn't bother me ... I think I'm okay with low-frequency noises." (#1)

The attitude towards one's neighbours could be formed by the influences of various conditions. For example, as the quote above shows, Interviewee #1 mainly talked about noise sensitivity and the type of noise source. He said he was "very sensitive to noise" but he was "fine" with his current upstairs neighbours because he was "okay with low-frequency noises". There were different conditions reported by different interviewees and all of those conditions had significant impacts on their own attitudes towards their neighbours. Many of the conditions found in this study were in accordance with the existing suggestions of those which have significant impacts on subjective responses to noise (e.g. Lercher, 1996; Guski, 1999; Stallen, 1999; Laszlo et al., 2012). Table 8-4 lists the conditions categorising them into non-acoustic and acoustic factors. The non-acoustic factors are then categorised into demographical, personal/social, and situational factors based on the review provided by Laszlo et al. (2012). The list in the table is sorted in alphabetical order in each category.

Table 8-4. Conditions influencing the attitude towards the neighbours.

Non-acoustic factors	Demographical	▪ Children at home ▪ Length of residency
	Personal/social	▪ Attitude shown by the neighbours ▪ Attitude towards the house ▪ Belief/expectancy ▪ Noise sensitivity ▪ Past experience/history ▪ Predictability/uncertainty of noise exposure ▪ Priority/goal
	Situational	▪ Children at the neighbours home ▪ Hours spent at home ▪ Time of noise exposure
Acoustic factors		▪ Ambient noise ▪ Frequency/interval of noise exposure ▪ Length/duration of the noise event ▪ Noise level ▪ Noise source

The interviews were carried out with open-ended questions so the interviewees expressed their personal experiences, thoughts, and feelings using their own terms and in their own ways. The whole interviews were led by their own narratives and the author did not guide them to talk about certain topics. As a result, three of the conditions became conspicuous from the interviews. Hence, this chapter places emphasis on the three conditions. The first condition is the attitude shown by neighbours. The second condition is past experience/history. The third condition is the predictability/uncertainty of noise exposure. Appendix 6 presents additional interview quotes which implied other conditions shown in Table 8-4.

8.3.3.1 Attitude shown by neighbours

> "I had bad experiences [with previous neighbours] when I lived in my previous house ... I called the police one night ... I was really, really angry ... I had already called the management office so many times ... The relationship [between the neighbours and me] got worse since then ... So I didn't want to talk to them [the current neighbours] when they moved in. Who knows? They could be the same [with previous neighbours]. But they [the current neighbours] seem okay, [they are] quite friendly." (#15)

Interviewee #15 changed his attitude due to the attitude which was shown by his neighbours ("they seem okay, [they are] quite friendly."). This implies that his positive attitude towards his neighbours was formed because they seemed "quite friendly". This section particularly discusses the impact of the attitude shown by the neighbours by assuming that it has a significant reciprocal inter-relationship with the interviewees' attitude towards their neighbours.

> "I'll always remember the date and time, it was October 21st two years ago, it was 1:15 am. I went upstairs, knocked on the door and rang the bell several times until she opened the door. I told her they had been very noisy for many hours and that it was too late. However, she stopped me talking and shouted at me, saying that I didn't know how to get along with neighbours in this type of housing. I came back [home] and called the police ... They have been noisy so many times and I have put up with them for so long. The management office had contacted them several times before but they never changed ... We don't see each other even in the same

> lift. I don't want to see them. I really hope they'll move out ... I haven't seen anyone like them before." (#46)

Attitude is a separate entity from emotion, cognition, and behaviour (e.g. Breckler, 1984; Crites Jr et al., 1994). Emotion and cognition refer to the feelings (positive or negative) and belief that the individual hold towards an object. Behaviour indicates the overt actions and responses to the object (Fabrigar et al., 2005). Attitude is a general evaluative summary of the information derived from the emotion, cognition, and behaviour (e.g. Breckler, 1984). As the quote above implies, Interviewee #46 had built a negative attitude towards her neighbours. The negative attitude was formed by the chronic noise exposure ("so many times"), by putting up with them "for so long", by having made noise complaints "several times", and experiencing the goal blockage ("they never changed"). The attitude shown by her neighbours late at night would have had a significant impact on her attitude formation. Her neighbour "stopped" her talking and shouted at her, saying that she "didn't know how to get along with neighbours". The behaviours shown by the neighbour involved negative emotional expressions. In particular, the anger expressions from the neighbour would have had an impact on the interviewee's emotion, cognition, and behaviour (van Kleef et al., 2011). First, Interviewee #46 developed anger and hatred (emotion) towards their neighbours. These emotions were easily identified from her tone of the voice during the interview, especially when she talked about her experience, particularly that on the day of the incident. Second, she believed that the neighbours were wrong. Fritz (1958) proposed the attribution theory, consisting of internal and external attributions. Internal attribution directs the cause of a certain behaviour or incident towards something within the individual (e.g. personality of the person), whereas external attribution directs to something external (e.g. situational factor). Interviewee #46 blamed the neighbours by adopting internal attribution (e.g. "I haven't seen anyone like them before"). Lastly, the anger expression of the neighbour led her to call the police (behaviour) and the perceived emotion and cognition resulted in certain patterns of behaviour (e.g. not making any eye-contact with them).

> "Who can spit at a smiley face? ... They brought some fruit when they first moved in and apologised as they have children ... they have brought cakes, juice, fruit since then ... I've told them that they do not need to do so [bring something] several times but they keep bringing something and keep apologising every time I see them in the lift ... I know they are good people, but I think I'm quite sensitive ... Sometimes, when I'm tired, I'm annoyed by the noise of kids running, but I just can't tell them. I feel sorry." (#49)

Interviewee #49 could not make any complaint to their neighbours, even though she had been annoyed by the noise of the children upstairs running. She had chosen the internal attribution, directing it towards herself ("I know they are good people, but I think I'm quite sensitive"). This was mainly because of her neighbours' attitude. The neighbours had been apologetic since they first moved in. Their apologetic attitudes were expressed by their behaviour. The neighbours were that they kept "bringing something" to her and "apologising" every time she met them in the lift. The neighbours' attitude of being apologetic and the consistency of the attitude influenced her attitude formation. The neighbours' attitude made her reluctant to "spit at a smiley face" and so she adopted the internal attribution regarding her annoyance. The quote above shows that there was another condition, priority, which could also have had an impact on her attitude. Interviewee #49 might have chosen to adopt internal attribution because her priority to maintain the positive relationship with the neighbours ("good people") was greater than the one to reduce her annoyance.

8.3.3.2 Past experience/history

In the previous section (Subchapter 8.3.3.1), the quote of Interviewee #15 was presented. When Interviewee #15 was living in his previous house, he experienced anger due to the continuous noise from his previous neighbours (emotion) and called the police (behaviour). This experience made him believe that other neighbours would be the same (cognition). Thus, Interviewee #15 presented a negative attitude towards the current neighbours at first based on the information derived from his past emotion, cognition, and behaviour.

> "I don't mind it. They [children upstairs] are just kids and it's very difficult to control them, I know that. My children did the same, kids just run all the time." (#56)

Interviewee #56 also developed her attitude towards her neighbours based on her personal history. The experience of living with children in the past had made her understanding of the children's noise from upstairs ("My children did the same, kids just run all the time"). This quote also supports the previous finding that those living with children are likely to be more empathetic to children's noise when it is coming from their neighbours (Park et al., 2016a). Given that children's footstep noise was one of the most common noise sources in multi-family residential buildings (Chapter 3), the residents living with children or those who have previously lived with children may be also more empathetic to other noises from their neighbours. This is because shared experience develops an individuals' empathy (Hodges et al., 2010).

> "I've asked the [management] office quite a few times to ask them [neighbours] to be quiet. She [management officer] said they would [stop making noise] ... I ended up calling them [neighbours] last night as they didn't stop [making noise] ... I think I'll be very upset if I have to ask them to be quiet again. I'll have to wait and see." (#40)

Individuals' attitudes are consistently formed and developed based on their belief in relation to their memory (Ajzen and Fishbein, 2000). The above quote implies that the negative attitude towards the neighbours gradually developed, as Interviewee #40 had repeatedly complained about the noise. In particular, she had heard the noise even after the management office contacted her neighbours. This example could be explained using the expectation-disconfirmation approach (Oliver, 1977). According to the expectation-disconfirmation theory, a positive disconfirmation occurs when the outcome is perceived to be better than expected. On the other hand, a negative disconfirmation occurs when the outcome is perceived to be worse than expected. As shown in the quote above, Interviewee

#40 showed a negative disconfirmation because the actions of the neighbours did not meet her expectations and goal, which is referred to as an outcome that is personally significant (Lazarus, 1991; Scherer, 2001). Moreover, the accumulated experiences of negative disconfirmation might have changed her behaviour ("I ended up calling them"). She could contact the neighbours directly in the future rather than doing the same as before (i.e. indirect complaint). Her past experience also led her to develop the emotion of anger ("I think I'll be very upset if I have to ask them to be quiet again.") because anger is evoked when goals are blocked (Lewis, 1993).

8.3.3.3 Predictability/uncertainty of noise exposure

> "They are quite nice people. I am totally fine with them ... they always come down and tell us in advance if something's happening, like a family gathering or a party with friends ... [neighbours have people around] once every month or two." (#44)

The quote above also emphasises how the neighbours' attitude helps to develop the resident's attitude. The positive attitude of Interviewee #44 would have been influenced by his neighbours' attitude and behaviour. This is because the neighbours had (1) always (2) come downstairs and (3) told him about the occurrence of noise events in advance. However, in addition to the attitude shown by the neighbour, the predictability of the noise event was also influenced the interviewee's attitude. The interviewee could "always" predict the time and type of noise event. In addition, the noise exposure was not frequent since the noise events occurred "once in a month or, every two months". Thus, a predictable noise from the neighbour would have been less annoying than noise from an unknown origin (Levy-Leboyer and Naturel, 1991). Other previous studies have also reported that unpredictable stressors evoke negative mood states and a high level of arousal (e.g. Berkowitz, 1969; Poulton, 1978). Compared to predictable stressors, unpredictable stressors are more threatening. Thus, unpredictable stressors require a greater degree of adaptation which involves a greater amount of adaptive effort in turn

(Glass and Singer, 1972). Moreover, as individuals monitor the potentially threatening stressors in order to evaluate their adaptive significance and to decide on appropriate coping responses, prolonged exposure to such stressors may result in cognitive fatigue (Cohen and Spacapan, 1978). Accordingly, for Interviewee #44, the adaptive effort was not frequently required and there was a low risk of cognitive fatigue.

8.3.4 How attitude results in coping

It was observed that the most commonly adopted coping strategy was making a complaint. More than half of the interviewees had made complaints about their neighbours' noises. Details of the complaints made by each interviewee have been listed in Appendix 6. Specifically, there were various ways of making complaints about neighbour noise and there were different degrees of complaints. Some residents had made complaints to management offices or to the local authorities (indirect complaint), whereas others had complained directly to the neighbours by visiting their houses or hitting the ceiling in order to make a retaliatory noise. Those who had not made any noise complaints used other coping strategies. For example, they tried to find something to distract them from noise exposure such as watching TV or going out for a walk. However, there were still some who had not undertaken any action and merely put up with the noise exposure. People's attitudes guide and motivate their thoughts and behaviour (Eaton et al., 2008). The residents' different attitudes towards their neighbours guided and motivated them to choose different coping strategies, including cognitive and behavioural copings. Table 8-5 summarises the different coping strategies along with different attitudes. There are three major coping strategies (cognitive, avoidant, and vigilant coping) associated with the different types of complaint and action details. Furthermore, three different attitudes in Figure 8-2 were added to this table in order to suggest the impact of attitude on copings.

Table 8-5. Variations of the coping strategies undertaken by the residents with different attitudes towards the neighbours. Coping strategies that are highly likely to be taken on are marked with circles (○), those that may or may not be taken on are marked with triangles (△), and those unlikely to be taken on are marked with crosses (×).

Coping strategy		Type of complaints	Action details		Friend	Stranger/Acquaintance			Enemy
						Positive	Neutral	Negative	
Cognitive		No complaint	No action	Empathy	○	○	○	○	×
				Repression	△				
Behavioural	Avoidant		Being self-distracted: going out, turning on the TV/radio						
			Noise cancelling actions: using earplugs						△
	Vigilant	Indirect complaints	Contacting the management office		×	△			○
		Direct complaints	Contacting the neighbours: visit, phone-call, letter		○		△		
			Making official complaints: police, government authority		×	×			
			Taking retaliatory behaviours: making revengeful noise, violent behaviour				×	×	

> "I went upstairs on the day I was moving in. I brought some cake. They asked me to come in and we spent about an hour talking, having tea and the cake I brought ... I'm lucky to have such good friends as my neighbours ... I can understand [the noise exposure]. Everyone makes noise in their everyday life." (#7)

> "They are very social, we became friends not so long after they moved in ... I just call them and say 'hey, can you please be quiet?'" (#24)

Those who regarded their neighbours as friends tended to take no action, but they were understanding and empathetic (cognitive coping). Empathy is an attempt at understanding the subjective experiences of another person without prejudice (Wispé, 1986). This attitude leads individuals to build or maintain a positive relationship with others (Zaki and Ochsner, 2016). Therefore, one of their priorities may be to build or maintain positive relationships with their neighbours. Interviewee #7 "brought some cake" to her neighbours on the day that she moved in. Her action implies that her priority was to build a good relationship with her neighbours. The neighbours' response and behaviour ("They asked me to come in") also contributed to building a constructive relationship. This case again confirms the impact of the positive attitude shown by the neighbours. Residents can still be annoyed by noise from the neighbours who are regarded as a 'friend'. However, as presented in the quote of Interviewee #24, the reaction will be different from the reaction to noise from neighbours who they have a negative relationship (e.g. 'enemy'). The tone of the complaint would be in a friendly way and noise complaints between friends can be understood as 'asking for a favour' rather than 'making a complaint'.

> "I've done everything ... Anything I can do to solve this problem ... I've called the centre [Floor Noise Management Centre] and they said they could come and measure the noise level and see if the levels exceed that in the regulation ... that means they [upstairs neighbours] should make noise when the people from the centre come. How can I predict they [upstairs

> neighbours] will make noise? I have no idea when they are going to make noise, that's why I get crazy ... It seems the centre is for those who have problems between neighbours to mediate the disputes." (#51)

Those who consider their neighbours as strangers or acquaintances will take on a wide range of coping strategies. If they have a positive affect towards the neighbours, then they are likely to use cognitive and avoidant coping strategies. Cognitive coping includes empathy and repression; those who have empathy with their neighbours are actively and pleasantly understanding their neighbours, while people who have repression tend to be passively understanding and put up with the noise without taking action. Avoidant coping strategies include several actions which may not be recognised by the neighbours. For example, some people choose to go out and have a walk or turn on the TV or radio which can be used to distract themselves from the noise. Others take noise cancelling actions such as using earplugs. They may or may not contact the management office (indirect complaint) or the neighbours themselves, but it would be in a polite way. The coping strategies transform into being more direct and unfriendly as the attitude becomes more negative. As noted earlier, the changes in the affect are influenced by different conditions (e.g. past experience of noise exposure). Table 8-5 presents that residents who regard their neighbours as strangers or acquaintances with a negative affect are likely to choose actions to cope with the noise. For instance, Interviewee #51 tried many things, covering not only cognitive strategies but also most of the behavioural coping strategies. Since his main goal was to solve the noise problem, he had done "anything" he could to solve the problem.

> "They made me crazy. They never stop ... I think I can understand why those people on TV killed their neighbours. I'm not saying I want to do something to harm them [upstairs neighbours] but I'm just saying that I know how they [people on the news who committed the crime to their neighbours] might have felt ... There are many holes in my ceiling as I've hit my ceiling with a golf club. I know it's destroying my house ... I can't put up with them. I'm 100 per cent sure they make noise intentionally ...

> jumping with shoes, heels! Have you seen anybody wearing shoes in their house ... It's a headache ... I think of what I should do with them every day ... I've installed three loudspeakers on my ceiling. They work quite well ... I turn them [the speakers] on if they [neighbours] are noisy at night." (#35)

For neighbours who are regarded as enemies, people are likely to choose more vigilant coping strategies. They may not choose coping strategies which are not recognised by their neighbours because their coping behaviours aim to express their anger and threaten their neighbours (e.g. retaliatory actions). Their tone and gestures of complaints become more aggressive as the affect gets more negative. Individuals perceive anger when they judge attacking as a viable option to restore the unfavourable situation (Lazarus, 1991). Anger is associated with a desire to change the situation and an aggressive tendency against the person who is seen to cause the goal blockage (van Kleef et al., 2010). Interviewee #35 had hit his ceiling with a golf club and played noise via three loudspeakers as retaliatory actions. He also said that he could "understand why those people on TV killed their neighbours". His negative attitude towards his neighbours and his retaliatory actions can be partially explained by the attitude shown by his neighbours. He believed that the neighbours had made intentional noise because he had heard jumping noises with shoes on, which is unlikely in Korea. The inappropriate attitude of the neighbours would have deepened his negative attitude, and consequently resulted in more revengeful behavioural coping strategies.

8.3.5 General discussion

This study has explored the attitudes towards their neighbours, the coping strategies used, and the broader conditions. However, further study is required to investigate the residents' coping methods. First of all, it is still questionable whether or not residents choose different coping strategies based on their neighbours' demographic characteristics. Since the individual's attitude towards some characteristics (e.g. gender) have been found to involve prejudice and stereotype

(Eagly and Mladinic, 1994), further research could examine how attitude and coping vary according to the neighbours' demographic qualities. Second, the residents in multi-family residential buildings are living in the same community and neighbourhood. It has been known that a sense of community or social cohesion has an important role in increasing social interaction between neighbours (Unger and Wandersman, 1985; Farrell et al., 2004; Kim and Kaplan, 2004). Future research could test the existing suggestions to see if a sense of community increases social ties and supportive acts between neighbours (Skjæveland et al., 1996; Henry et al., 2014; Rollwagen, 2016), and thereby if the sense of community has a potential impact on resolving disputes and conflict between neighbours. Third, it has been known that various situational factors have an impact on how individuals manage their interpersonal conflicts (e.g. Rahim, 1986; Volkema and Bergmann, 1995). The different styles of conflict management have been classified into five styles in a model with two dimensions of concern; for others (i.e. cooperativeness) and concern for the self (i.e. assertiveness). It is worth adopting the idea that when future research focuses on neighbourly disputes and conflict. Fourth, this study has presented a paradigm between the key concepts based on the transactional model of stress as suggested by Lazarus and Folkman (1984). The model originally includes the secondary appraisal. As a secondary appraisal, environmental noise studies have suggested that perceived control has a significant impact on coping (e.g. van Kamp, 1990; Lercher, 1996; Botteldooren et al., 2016). Future research could investigate how to properly measure perceived control related to neighbour noise, and how much perceived control influences the residents' reaction to the noise. The assessments of perceived control are expected to extend the existing understanding of the diverse responses to neighbour noise.

8.4 Summary

Attitude towards environment noise has been reported to influence subjective responses and coping strategies. However, no attempt has been made to understand the attitude towards noise source in the research field of neighbour noise. This study aimed to fill the gap in the existing research by investigating the role of attitude towards neighbours. Utilising a qualitative approach of grounded theory methods, in-depth interviews with 57 residents in multi-family housing were carried out. This study explored how residents' attitudes towards their neighbours would be formed. The study proposed that the residents' perceived affect towards their neighbours (positive or negative) and its intensity (from weak to strong) had impacts on their attitudes towards their neighbours. The attitudes displayed towards the neighbours were grouped into stranger/acquaintance, friend, and enemy in terms of the affect and intensity. Among the various acoustic and non-acoustic conditions affecting attitudes, this chapter particularly highlighted the impact of the following three conditions: attitude shown by the neighbours, past experience/history, and predictability/uncertainty of noise exposure. This study also investigated how different attitudes resulted in different coping. The coping strategies consisted of cognitive coping and behavioural coping. Cognitive coping included repression and empathy, while behavioural coping included avoidant copings (e.g. using earplugs or going out) and vigilant copings (e.g. making direct noise complaints to the neighbours or making a retaliatory noise). The findings in this study confirmed and extended the previous research findings by demonstrating the significant role of attitudinal variable and the close relationship between the attitudinal variables and coping. Table 8-6 summarises the major findings of this study with the research question of the study.

Table 8-6. The research question and the findings of this study.

Research questions	Findings
▪ What factors have effects on the responses to floor impact noise?	▪ Different attitudes led to different coping strategies from cognitive to behavioural (avoidant and vigilant) copings. ▪ The individual's perceived affect towards their neighbours (positive or negative) and its intensity (from weak to strong) formed the attitude towards the neighbours. The study divided the attitudes into enemy, friend, or stranger/acquaintance. ▪ Attitudes shown by the neighbours, past experience/history, and predictability/uncertainty of noise exposure led to form the individual's attitude towards neighbours.

9 Conclusion

9.1 Findings of the research

This research work consists of six different studies. The studies were carried out in order to answer the three main research questions which were introduced in Subchapter 1.2.1.

9.1.1 Research question #1

> **What kinds of indoor noise would be heard from real residences in heavyweight multi-family housing buildings?**
>
> ⇨ Various noise sources were identified from the data. Given that each house showed different noise characteristics, not only slab thickness but also many other acoustic and non-acoustic factors would have impacts on the noise events. Different noise sources were exposed at different noise levels so future research may apply that and design the noise stimuli using various ranges of noise levels.

This question was mainly answered by investigating various noise events in real houses and identified each noise event's characteristics (e.g. noise level, noise source, noise length, and the number of occurrences). The overall L_{Aeq} ranged from

20.8 to 45.7 dBA for 24 hours and the overall L_{AFmax} ranged from 48.8 to 87.1 dBA for 24 hours. The identified indoor noise included different airborne and structure-borne noises. Airborne noise included the following noise sources: PA system, domestic equipment, adult's voice, children's voice, and others (e.g. musical instrument). Structure-borne noise contained heavyweight and lightweight impact noises. The heavyweight impact noise was comprised of adult's walking, children's running, and children's jumping. For the lightweight impact noise, the study identified movement of furniture, small object dropping, small object scraping, door banging, plumbing system, and hammering. The highest and lowest L_{AFmax} of structure-borne noise sources were generated by hammering and plumbing system, respectively. The noise level of the plumbing system considerably increased when L_{AE} was derived because of its long length. The greatest number of occurrence was identified with the following four noise sources: adult's walking, children's running, movement of furniture, and dropping of small objects. Median lengths of these four noises were from 5.5 to 31 seconds. Lengths of all the noise events ranged from 1.3 to 1,683 seconds. The shortest median and mean lengths were made by the door banging. The longest median and mean lengths were generated by the plumbing system. The slab thickness did not correlate with the noise characteristics and thus, other physical characteristics, as well as neighbours' activities, need to be considered as important determinants for the indoor noise events.

9.1.2 Research question #2

How do people respond to floor impact noise psychologically and physiologically?

⇨ The noise exposure increased noticeability, annoyance, and negative emotions (anger, dislike, and pain). It also evoked changes in HR, EDA, and RR implying potential adverse health effects. Blood pressure and health-related quality of life were affected by how residents perceive the indoor noise heard from their homes.

First of all, the laboratory studies examined noticeability and annoyance perceived by floor impact noise stimuli (i.e. psychological responses), as well as heart rate, electrodermal activity, and respiration rate responses to floor impact noise stimuli (i.e. physiological responses). The stimuli presentation had significant impacts on all the responses. As noise levels increase, noticeability and annoyance increased, heart rate decelerated, electrodermal activity increased, and respiration rate accelerated. Then the changes in emotions were examined when the floor impact noise stimuli were heard. Four emotion clusters were classified: anger, dislike, pain, and empathy. The emotion clusters were then tested in a laboratory setting. The emotion clusters were affected by the noise level and significantly correlated with annoyance. The findings were tested and validated in the following field study. In addition, blood pressure and health-related quality of life were influenced by annoyance, emotions, and indoor noise satisfaction. It was found that those who reported higher negative responses to floor impact noise had higher blood pressure and reported worse quality of life. However, the quality of life and blood pressure could not be regarded as the 'responses to floor impact noise' because there were a number of intertwined factors affecting the quality of life and blood pressure.

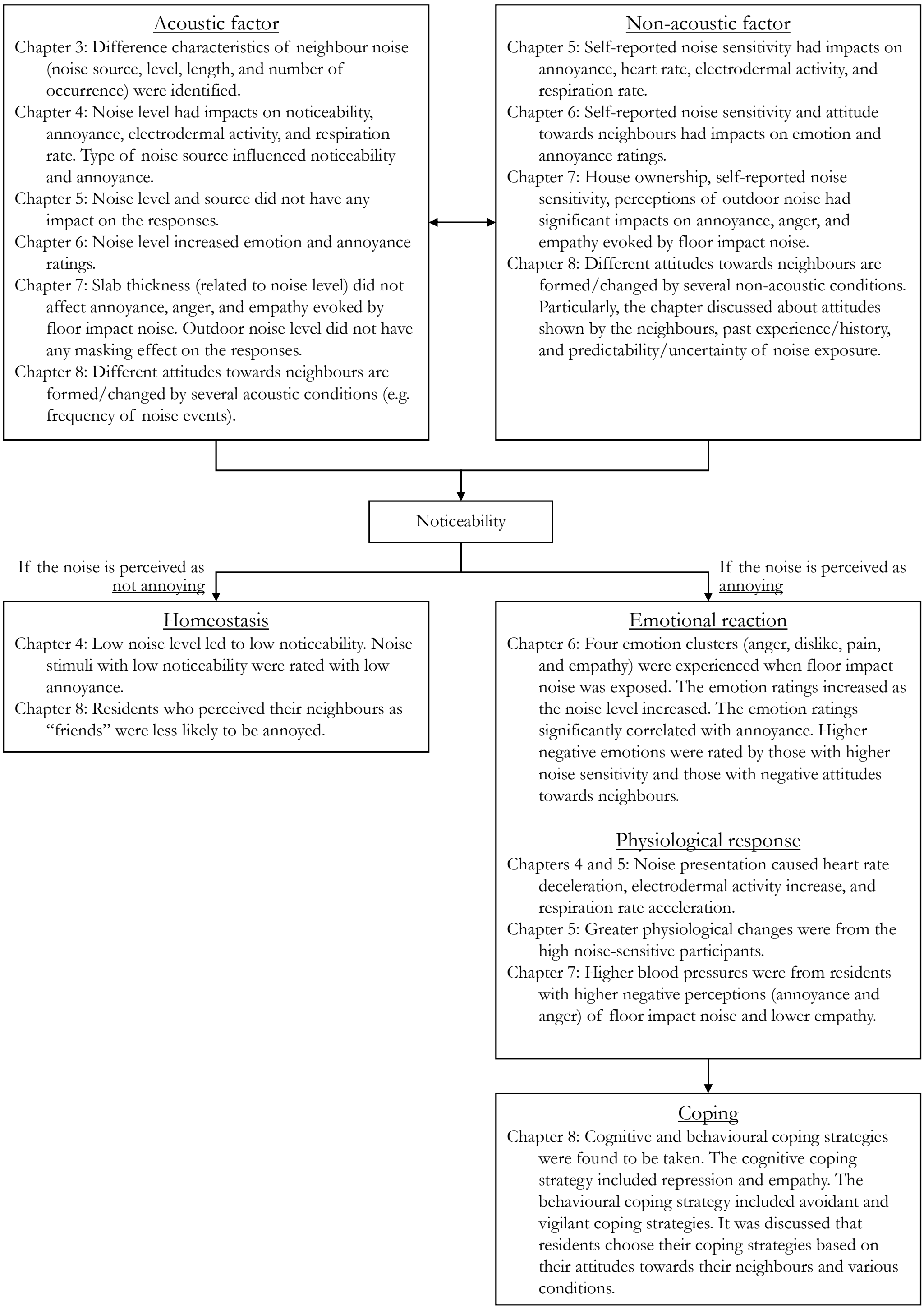
9.1.3 Research question #3

What factors have impacts on the responses?

⇨ Different noise levels changed noticeability, annoyance, and emotions. However, their impacts on the physiological changes remain unclear. Different impact noise sources had impacts on noticeability and annoyance but not on the physiological responses. Noise sensitivity showed significant effects on all the responses. Attitude to neighbours and some socio-demographic factors (e.g. house ownership or financial investment) were discussed as important factors but further investigations are needed.

In order to find answers to this question, various acoustic and non-acoustic factors were tested in different studies. First, Chapter 3 examined the effect of slab thickness on the noise level which potentially had impacts on the psychological and physiological responses. The study found that the slab thickness did not have any correlation with the noise level. Later Chapter 7 partially supported this result by showing that there was no significant impact of the slab thickness on the psychological responses to indoor noise. Second, Chapters 4 ~ 6 assessed the effect of the noise level. It was revealed that the psychological responses were significantly affected by the noise level. Self-reported noticeability, annoyance, anger, dislike, and pain increased as the noise level increased; empathy decreased as the noise level increased. However, the effect of the noise level on physiological responses was not consistent. Third, Chapter 5 examined the effect of the duration of noise exposure by playing the stimuli for 5 minutes. The physiological responses showed habituation or recovery when the length of noise exposure lasted longer. Fourth, the laboratory studies (Chapters 4 and 5) evaluated the impacts of different types of the noise source. Both studies in Chapters 4 and 5 used the real and standard impact noise stimuli as the floor impact noise stimuli. Additionally, Chapter 5 presented the road traffic noise stimulus. It was discussed that the length of stimuli might have affected the changes in the responses because of the following results. The standard impact noise evoked higher noticeability and annoyance than the real impact noise when the stimuli were heard for short time (23 seconds). However, the real impact noise was rated with higher annoyance than the standard impact noise when the stimuli were presented longer (5 minutes) and the standard impact noise simulated real footstep noise. For the physiological responses, they were not significantly different from each other between the real and standard impact noise stimuli. However, a clearer difference between the noise-sensitivity groups was found when the floor impact noise stimuli were presented compared with the road traffic noise stimuli exposure. Fifth, the effects of various personal factors were tested in Chapters 5 ~ 7. The participants who had higher self-reported noise sensitivity reported greater annoyance, anger, dislike, pain, and empathy.

Furthermore, the participants with higher noise sensitivity presented greater changes in heart rate, electrodermal activity, and respiration rate. Likewise, the participants with negative attitudes towards their neighbours presented greater annoyance, anger, dislike, pain, and empathy. However, the difference between the positive and negative attitude groups was not as clear as that of noise-sensitivity groups. Additionally, there was no significant impact of attitudes towards neighbours on the physiological responses. Given that attitude towards neighbours have been assumed to play an important role in neighbour noise responses, Chapter 8 further explored how one's attitude towards the neighbours is formed and changed. Attitude towards neighbours was formed by various conditions. Particularly, the attitude shown by the neighbours, past experience/history, and predictability/uncertainty of noise exposure were discussed to have impacts on one's attitude. Different attitudes towards the neighbours were suggested to result in different coping strategies when residents are exposed to neighbour noise. Sixth, Chapter 7 examined the impacts of outdoor noise level and annoyance of the outdoor noise. The outdoor noise level did not have any significant impact on the responses but the annoyance of outdoor noise had significant correlations with the psychological responses to indoor noise. Given that those who reported higher annoyance of outdoor noise also reported higher negative responses to indoor noise, it was discussed that their noise sensitivity might have affected the responses. Figure 9-1 illustrates the findings from the studies in the diagram. The diagram is developted based on one of the stress models (Figure 2-3) which this thesis introduced earlier.



Acoustic factor

Chapter 3: Difference characteristics of neighbour noise (noise source, level, length, and number of occurrence) were identified.

Chapter 4: Noise level had impacts on noticeability, annoyance, electrodermal activity, and respiration rate. Type of noise source influenced noticeability and annoyance.

Chapter 5: Noise level and source did not have any impact on the responses.

Chapter 6: Noise level increased emotion and annoyance ratings.

Chapter 7: Slab thickness (related to noise level) did not affect annoyance, anger, and empathy evoked by floor impact noise. Outdoor noise level did not have any masking effect on the responses.

Chapter 8: Different attitudes towards neighbours are formed/changed by several acoustic conditions (e.g. frequency of noise events).

Non-acoustic factor

Chapter 5: Self-reported noise sensitivity had impacts on annoyance, heart rate, electrodermal activity, and respiration rate.

Chapter 6: Self-reported noise sensitivity and attitude towards neighbours had impacts on emotion and annoyance ratings.

Chapter 7: House ownership, self-reported noise sensitivity, perceptions of outdoor noise had significant impacts on annoyance, anger, and empathy evoked by floor impact noise.

Chapter 8: Different attitudes towards neighbours are formed/changed by several non-acoustic conditions. Particularly, the chapter discussed about attitudes shown by the neighbours, past experience/history, and predictability/uncertainty of noise exposure.

Homeostasis

Chapter 4: Low noise level led to low noticeability. Noise stimuli with low noticeability were rated with low annoyance.

Chapter 8: Residents who perceived their neighbours as "friends" were less likely to be annoyed.

Emotional reaction

Chapter 6: Four emotion clusters (anger, dislike, pain, and empathy) were experienced when floor impact noise was exposed. The emotion ratings increased as the noise level increased. The emotion ratings significantly correlated with annoyance. Higher negative emotions were rated by those with higher noise sensitivity and those with negative attitudes towards neighbours.

Physiological response

Chapters 4 and 5: Noise presentation caused heart rate deceleration, electrodermal activity increase, and respiration rate acceleration.

Chapter 5: Greater physiological changes were from the high noise-sensitive participants.

Chapter 7: Higher blood pressures were from residents with higher negative perceptions (annoyance and anger) of floor impact noise and lower empathy.

Coping

Chapter 8: Cognitive and behavioural coping strategies were found to be taken. The cognitive coping strategy included repression and empathy. The behavioural coping strategy included avoidant and vigilant coping strategies. It was discussed that residents choose their coping strategies based on their attitudes towards their neighbours and various conditions.

Figure 9-1. A summary of the findings from the present research.

9.2 Future research directions

There are remaining questions which have not been answered in this research. There is a need for conducting both indoor noise measurements as well as the assessment of occupants' subjective responses to the indoor noise. It has been common to report dose-response relationships in the environmental noise research fields using 24-hour noise levels and subjective responses to the noise but there has been no attempt made to explain the relationship of neighbour noise, particularly of floor impact noise. It is recommended for future noise measurements to cover various months of the year in order to examine the effects of different seasons. Since residents usually leave windows open in the warm seasons, airborne noises from neighbours would be different between the warm and cold seasons. Further, the measurements in different months are needed because children's activities may be different between the school term times and holiday times. Therefore, longitudinal measurements have been suggested for future research to cover the various circumstances of the year. In addition, more investigations are needed into various physical characteristics of the construction as it was found that slab thickness itself cannot explain the different characteristics of the noise exposure. There are non-acoustic variables which need to be considered more in-depth (e.g. financial investment or social cohesion) in order to further understand the responses to the noise. It has been examined how sound environments and architectural characteristics may contribute to indoor soundscape of several public spaces such as libraries or hospitals (e.g. Good and Roy, 2010; Yorukoglu and Kang, 2016). It is expected that the findings of this research and future investigations into the residential noises would yield further insights into understanding of how to build pleasant indoor soundscape in residential spaces.

Second, further investigations are needed into coping and its potential impacts on neighbour disputes and conflicts. It is still uncertain whether or not residents choose different copings based on 'who they (neighbours) are'. In other words, some demographic characteristics (e.g. age or gender) of the neighbours may influence the individual to choose different coping strategies. Given that the sense of community plays an important role in increasing social interaction between neighbours, further research on the way to improve it in the community of multi-family housing and its effect need to be carried out. Besides, the traditional stress theory has suggested that primary and secondary appraisals have impacts on the individual's coping (Lazarus and Folkman, 1984). In particular, existing environmental noise studies have acknowledged perceived control as the secondary appraisal but the investigation has not been carried out in neighbour noise studies. Thus, future research may examine whether perceived control can be the secondary appraisal in neighbour noise issue. If so, it could investigate how to measure perceived control of residents as to the issue of neighbour noise and evaluate its role on residents' future coping strategies which have potential impacts on neighbour disputes or conflicts. Furthermore, the environmental stress theory (Bell et al., 1990) proposed that various consequences are resulted by different copings and the consequences again influence the individual's perception. Future research may examine what kinds of consequences can be caused by residents' different copings and how the consequences influence their reactions to neighbour noise.

Third, emotions were examined when floor impact noise, particularly human-made footstep noise was presented. Given that there are a number of different sources of neighbour noise, future research may examine emotions evoked by different noise sources including both airborne and structure-borne noise sources. There is also a need for future research that involves various study settings in which other measurements can be undertaken to examine the emotions. The assessments of task performance or physiological responses would yield further and broader understanding of the emotional states.

Last but not least, cross-cultural research is needed to examine if the findings in this study can be applied in other countries. Given that this research investigated indoor noise characteristics of residences in South Korea, future investigation is needed to see how they are different among various countries if physical factors of the house are controlled (e.g. heavyweight multi-family housing buildings in several countries). Moreover, residents' psychological and physiological responses need to be compared in order to explore what factors have influences on the responses. Since neighbour noise is not a social problem only in South Korea, research on emotions in different cultures using different languages would be helpful to understand the issue more generally. Table 9-2 summarises the research questions for future research suggested above.

Table 9-1. Research questions for future research.

Research question
Indoor noise measurement ▪ How would the noise level relate to subjective responses to the noise? ▪ Would the noise events be different between different times of the year? (e.g. different seasons, school term times vs. holiday times, etc.) ▪ How can the findings in this research be extended to the research field of indoor soundscape?
Coping evaluation ▪ How would residents' coping be affected by demographic characteristics of neighbours? ▪ How would the sense of community influence residents' copings? ▪ How to measure the perceived control as a secondary appraisal and how the perceived control influence residents' coping? ▪ How consequences resulted from different coping again influence residents' responses?
Emotion measurements ▪ Would different neighbour noise sources result in different emotions? ▪ How would measurements of performance and physiological responses add further evidence in research on emotion towards neighbour noise?
Cross-cultural study ▪ Would the findings in this research can be applied in other countries? ▪ What would be the differences between South Korea and other countries when it comes to indoor residential noise characteristics? ▪ Would residents in different countries show different psychological and physiological responses to floor impact noise or to neighbour noise? If so, how would they be different?

Bibliography

Abdullah, A., Marzbali, M. H., and Tilaki, M. J. M. (2013) "Predicting the influence of CPTED on perceived neighbourhood cohesion: Considering differences across age" Journal of Environmental Psychology 36 pp. 54-64.

Abo-Qudais, S., and Abu-Qdais, H. (2005) "Perceptions and attitudes of individuals exposed to traffic noise in working places" Building and Environment 40 (6), pp. 778-787.

Ahn, S. H., Lee, S. H., and Kwon, O. S. (1993) "Activation dimension: A mirage in the affective space?" Korean Journal of Social and Personality Psychology 7 (1), pp. 107-123.

Ajzen, I., and Fishbein, M. (2000) "Attitudes and the attitude-behavior relation: Reasoned and automatic processes" European Review of Social Psychology 11 (1), pp. 1-33.

Aldwin, C. M. (2007) Stress, Coping, and Development: An Integrative Perspective, Guilford Press.

Alvarsson, J. J., Wiens, S., and Nilsson, M. E. (2010) "Stress recovery during exposure to nature sound and environmental noise" International Journal of Environmental Research and Public Health 7 (3), pp. 1036-1046.

Andrén, L., Hansson, L., Björkman, M., and Jonsson, A. (1980) "Noise as a contributory factor in the development of elevated arterial pressure" Acta medica Scandinavica 207 (1-6), pp. 493-498.

Atkin, J. (2017) "What type of housing do people live in?" [online] Available at: https://www.mortgagefinancegazette.com/market-news/housing/type-housing-people-live-11-08-2017/ [Accessed 30 November, 2017]

Atkinson, L. D., and Peden-McAlpine, C. J. (2014) "Advancing adolescent maternal development: A grounded theory" Journal of Pediatric Nursing 29 (2), pp. 168-176.

Aydin, Y., and Kaltenbach, M. (2007) "Noise perception, heart rate and blood pressure in relation to aircraft noise in the vicinity of the Frankfurt airport" Clinical Research in Cardiology 96 (6), pp. 347-358.

Babisch, W. (2008) "Road traffic noise and cardiovascular risk" Noise & Health 10 (38), pp. 27-33.

Babisch, W., Pershagen, G., Selander, J., Houthuijs, D., Breugelmans, O., Cadum, E., Vigna-Taglianti, F., Katsouyanni, K., Haralabidis, A. S., and Dimakopoulou, K. (2013) "Noise annoyance: A modifier of the association between noise level and cardiovascular health?" Science of the Total Environment 452-453 pp. 50-57.

Babisch, W., and van Kamp, I. (2009) "Exposure-response relationship of the association between aircraft noise and the risk of hypertension" Noise & Health 11 (44), pp. 161-168.

Baek, G. O., Mun, D. H., Han, H. K., and Park, H. G. (2015) "Analysis of heavy-weight floor impact noise and vibration of concrete slabs in a residential building" in World Congress on Advances in Civil, Environmental, and Materials Research, Incheon, Republic of Korea.

Bakker, R. H., Pedersen, E., van den Berg, G. P., Stewart, R. E., Lok, W., and Bouma, J. (2012) "Impact of wind turbine sound on annoyance, self-reported sleep disturbance and psychological distress" Science of the Total Environment 425 pp. 42-51.

Baum, A., Singer, J. E., and Baum, C. S. (1982) "Stress and the environment" in Environmental stress, edited by Evans, G. W. Cambridge University Press, pp. 15-44.

Bell, P. A., Fisher, J. D., Baum, A., and Greene, T. C. (1990) Environmental Psychology, Holt, Rinehart, and Winston Inc.

Belojević, G., Jakovljević, B., and Aleksić, O. (1997) "Subjective reactions to traffic noise with regard to some personality traits" Environment International 23 (2), pp. 221-226.

Belojević, G., Jakovljević, B., and Slepcević, V. (2003) "Noise and mental performance: Personality attributes and noise sensitivity" Noise & Health 6 (21), pp. 77-89.

Belojević, G., Öhrström, E., and Rylander, R. (1992) "Effects of noise on mental performance with regard to subjective noise sensitivity" International Archives of Occupational and Environmental Health 64 (4), pp. 293-301.

Bentley, M. (1928) "Is "emotion" more than a chapter heading?" in Feelings and Emotions: The Wittenberg Symposium, edited by Reymert, M. L. Clark University Press, pp. 17-23.

Berglund, B., Berglund, U., and Lindvall, T. (1975) "Scaling loudness, noisiness, and annoyance of aircraft noise" Journal of the Acoustical Society of America 57 (4), pp. 930-934.

Berglund, B., and Lindvall, T. (eds) (1995) Community noise. Archives of the Center for Sensory Research. World Health Organization (WHO).

Berglund, B., Lindvall, T., and Schwela, D. H. (1999) "Guidelines for community noise" World Health Organization (WHO), Geneva, Switzerland.

Berglund, B., and Nilsson, M. E. (2006) "On a tool for measuring soundscape quality in urban residential areas" Acta Acustica United with Acustica 92 (6), pp. 938-944.

Berkowitz, L. (1969) Roots of Aggression: A Re-Examination of the Frustration-Aggression Hypothesis, Atherton Press.

Berntson, G. G., Uchino, B. N., and Cacioppo, J. T. (1994) "Origins of baseline variance and the law of initial values" Psychophysiology 31 (2), pp. 204-210.

Bijsterveld, K. (2003) ""The city of din": Decibels, noise, and neighbors in the Netherlands, 1910-1980" Osiris 18 (1), pp. 173-193.

Björk, E. A. (1986) "Laboratory annoyance and skin-conductance responses to some natural sounds" Journal of Sound and Vibration 109 (2), pp. 339-345.

Björk, J., Ardö, J., Stroh, E., Lövkvist, H., Östergren, P.-O., and Albin, M. (2006) "Road traffic noise in southern Sweden and its relation to annoyance, disturbance of daily activities and health" Scandinavian journal of work, environment & health 32 (5), pp. 392-401.

Bluhm, G., Nordling, E., and Berglind, N. (2004) "Road traffic noise and annoyance: An increasing environmental health problem" Noise & Health 6 (24), pp. 43-49.

Bolger, E. (1999) "Grounded theory analysis of emotional pain" Psychotherapy Research 9 (3), pp. 342-362.

Borgatti, S. (1996) "Introduction to grounded theory" [online] Available at: http://www.analytictech.com/mb870/introtoGT.htm [Accessed 27 April, 2016]

Botteldooren, D., Andringa, T., Aspuru, I., Brown, A. L., Dubois, D., Guastavino, C., Kang, J., Lavandier, C., Nilsson, M., Preis, A., and Schulte-Fortkamp, B. (2016) "From sonic environment to soundscape" in Soundscape and the Built Environment, edited by Kang, J., and Schulte-Fortkamp, B. CRC Press, pp. 17-41.

Botteldooren, D., and Lercher, P. (2004) "Soft-computing base analyses of the relationship between annoyance and coping with noise and odor" Journal of the Acoustical Society of America 115 (6), pp. 2974-2985.

Botteldooren, D., Lercher, P., and Verkeyn, A. (2003) "Noise annoyance and coping: A soft analysis" in International congress on noise as a public health problem, ICBEN, Rotterdam, Netherlands.

Boucsein, W. (2012) Electrodermal Activity, Springer.

Bowen, G. A. (2008a) "Grounded theory and sensitizing concepts" International journal of qualitative methods 5 (3), pp. 12-23.

Bowen, G. A. (2008b) "Naturalistic inquiry and the saturation concept: A research note" Qualitative research 8 (1), pp. 137-152.

Bradley, M. M., and Lang, P. J. (2000) "Affective reactions to acoustic stimuli" Psychophysiology 37 (2), pp. 204-215.

Bradley, M. M., and Lang, P. J. (2007) "Emotion and motivation" in Handbook of psychophysiology, edited by Cacioppo, J. T., Tassinary, L. G., and Berntson, G. G. Cambridge University Press, pp. 581-607.

Breckler, S. J. (1984) "Empirical validation of affect, behavior, and cognition as distinct components of attitude" Journal of Personality and Social Psychology 47 (6), pp. 1191-1205.

Bringer, J. D., Johnston, L. H., and Brackenridge, C. H. (2004) "Maximizing transparency in a doctoral thesis: The complexities of writing about the use of QSR* NVIVO within a grounded theory study" Qualitative research 4 (2), pp. 247-265.

Brodsky, A. E., O'Campo, P. J., and Aronson, R. E. (1999) "PSOC in community context: Multi-level correlates of a measure of psychological sense of community in low-income, urban neighborhoods" Journal of community psychology 27 (6), pp. 659-679.

Bronzaft, A. L. (2002) "Noise pollution: A hazard to physical and mental well-being" in Handbook of environmental psychology, edited by Bechtel, R. B., and Churchman, A. John Wiley & Sons, pp. 499-510.

Brosschot, J. F., and Thayer, J. F. (2003) "Heart rate response is longer after negative emotions than after positive emotions" International Journal of Psychophysiology 50 (3), pp. 181-187.

Brown, A. L., and van Kamp, I. (2009a) "Response to a change in transport noise exposure: A review of evidence of a change effect" Journal of the Acoustical Society of America 125 (5), pp. 3018-3029.

Brown, A. L., and van Kamp, I. (2009b) "Response to a change in transport noise exposure: Competing explanations of change effects" Journal of the Acoustical Society of America 125 (2), pp. 905-914.

Brown, S. C., Stevens, R., Troiano, P. F., and Schneider, M. K. (2002) "Exploring complex phenomena: Grounded theory in student affairs research" Journal of college student development 43 (2), pp. 173-183.

Bryant, A., and Charmaz, K. (2010) "Grounded theory research: Methods and practices" in The Sage handbook of grounded theory, edited by Bryant, A., and Charmaz, K. Sage, pp. 1-28.

Buckner, J. C. (1988) "The development of an instrument to measure neighborhood cohesion" American journal of community psychology 16 (6), pp. 771-791.

Cacioppo, J. T., Berntson, G. G., Larsen, J. T., Poehlmann, K. M., and Ito, T. A. (2000) "The psychophysiology of emotion" in The Handbook of Emotion, edited by Lewis, R., and Haviland-Jones, J. M. pp. 173-191.

Cacioppo, J. T., and Petty, R. E. (1981) "Electromyograms as measures of extent and affectivity of information processing" American Psychologist 36 (5), pp. 441-456.

Cacioppo, J. T., and Tassinary, L. G. (1990) "Inferring psychological significance from physiological signals" American Psychologist 45 (1), pp. 16-28.

Carter, N. L., and Beh, H. C. (1989) "The effect of intermittent noise on cardiovascular functioning during vigilance task performance" Psychophysiology 26 (5), pp. 548-559.

Cassidy, S. (2013) An exploration of the processes that underlie change in dramatherapy: A grounded theory analysis, University of Glasgow.

Cha, S. G., and Ko, C. W. (2013) "An analysis on the subjective response of floor noise at apartment houses in Daegu province" in Conference of The Korean Society for Noise and Vibration Engineering, KSNVE, Republic of Korea.

Charmaz, K. (2000) "Grounded theory: Objectivist and constructivist methods" in Handbook of qualitative research, edited by Denzin, N. K., and Lincoln, Y. S. Sage, pp. 509-536.

Charmaz, K. (2001) "Grounded theory: Methodology and theory construction" in International Encyclopedia of Social & Behavioral Sciences, edited by Smelser, N. J., and Baltes, P. B. Elsevier, pp. 6396-6399.

Charmaz, K. (2006) Constructing Grounded Theory: A Practical Guide Through Qualitative Analysis, Sage.

Charmaz, K. (2008) "Grounded theory" in Qualitative Psychology: A Practical Guide to Research Methods, edited by Smith, J. A. Sage, pp. 81-110.

Charmaz, K. (2014) Constructing Grounded Theory, Sage.

Chavis, D. M., Hogge, J. H., McMillan, D. W., and Wandersman, A. (1986) "Sense of community through Brunswik's lens: A first look" Journal of community psychology 14 (1), pp. 24-40.

Chen, K., and Chan, A. H. (2013) "Use or non-use of gerontechnology – a qualitative study" International Journal of Environmental Research and Public Health 10 (10), pp. 4645-4666.

Chiovitti, R. F., and Piran, N. (2003) "Rigour and grounded theory research" Journal of Advanced Nursing 44 (4), pp. 427-435.

Clore, G. L., Ortony, A., and Foss, M. A. (1987) "The psychological foundations of the affective lexicon" Journal of Personality and Social Psychology 53 (4), pp. 751-766.

Cohen, S. (1988) "Perceived stress in a probability sample of the United States" in The Social Psychology of Health, edited by Spacapan, S., and Oskamp, S. Sage, pp. 31-67.

Cohen, S., and Spacapan, S. (1978) "The aftereffects of stress: An attentional interpretation" Environmental psychology and nonverbal behavior 3 (1), pp. 43-57.

Cohen, S., and Weinstein, N. (1981) "Nonauditory effects of noise on behavior and health" Journal of social issues 37 (1), pp. 36-70.

Compas, B. E., Connor-Smith, J. K., Saltzman, H., Thomsen, A. H., and Wadsworth, M. E. (2001) "Coping with stress during childhood and adolescence: Problems, progress, and potential in theory and research" Psychological bulletin 127 (1), pp. 87-127.

Cooper, C. (2013) Problem-based learning and mental health nursing: A constructivist grounded theory, University of Sheffield.

Corbin, J. M., and Strauss, A. (2008) Basics of Qualitative Research: Techniques and Procedures for Developing Grounded Theory, Sage.

Costa Jr, P. T., Somerfield, M. R., and McCrae, R. R. (1996) "Personality and coping: A reconceptualization" in Handbook of Coping: Theory, Research, Applications, edited by Zeidner, M., and Endler, N. S. John Wiley & Sons, pp. 44-61.

Coyne, I., and Cowley, S. (2006) "Using grounded theory to research parent participation" Journal of Research in Nursing 11 (6), pp. 501-515.

Crites Jr, S. L., Fabrigar, L. R., and Petty, R. E. (1994) "Measuring the affective and cognitive properties of attitudes: Conceptual and methodological issues" Personality and Social Psychology Bulletin 20 (6), pp. 619-634.

Crook, C. W., and Kumar, R. L. (1998) "Electronic data interchange: A multi-industry investigation using grounded theory" Information & Management 34 (2), pp. 75-89.

Croy, I., Smith, M. G., and Persson Waye, K. (2013) "Effects of train noise and vibration on human heart rate during sleep: An experimental study" BMJ open 3 (5), p. e002655.

Cutcliffe, J. R. (2000) "Methodological issues in grounded theory" Journal of Advanced Nursing 31 (6), pp. 1476-1484.

Dansey, N. (2013) A grounded theory of emergent benefit in pervasive game experiences, University of Portsmouth.

Darwall, S. (1998) "Empathy, sympathy, care" Philosophical Studies 89 (2-3), pp. 261-282.

Davies, W. K. D., and Herbert, D. T. (1993) Communities within Cities: An Urban Social Geography, Belhaven Press.

Dawson, M. E., Schell, A. M., and Filion, D. L. (2007) "The electrodermal system" in Handbook of psychophysiology, edited by Cacioppo, J. T., Tassinary, L. G., and Berntson, G. G. Cambridge University Press, pp. 159-181.

de Coensel, B., Botteldooren, D., de Muer, T., Berglund, B., Nilsson, M. E., and Lercher, P. (2009) "A model for the perception of environmental sound based on notice-events" Journal of the Acoustical Society of America 126 (2), pp. 656-665.

de Vente, W., Olff, M., van Amsterdam, J. G. C., Kamphuis, J. H., and Emmelkamp, P. M. G. (2003) "Physiological differences between burnout patients and healthy controls: Blood pressure, heart rate, and cortisol responses" Occupational and Environmental Medicine 60 pp. 54-61.

Department for Environment Food and Rural Affairs (2015) Survey of noise attitudes (SoNA) 2013. Department for Environment, Food and Rural Affairs (Defra), UK.

Dignan, J., Sorsby, A., and Hibbert, J. (1996) Neighbour Disputes: Comparing the Cost-Effectiveness of Mediation and Alternative Approaches, Centre for Criminological and Legal Research, Faculty of Law, University of Sheffield.

Dratva, J., Zemp, E., Dietrich, D. F., Bridevaux, P.-O., Rochat, T., Schindler, C., and Gerbase, M. W. (2010) "Impact of road traffic noise annoyance on health-related quality of life: Results from a population-based study" Quality of life research 19 (1), pp. 37-46.

Dunne, C. (2011) "The place of the literature review in grounded theory research" International Journal of Social Research Methodology 14 (2), pp. 111-124.

Dzhambov, A., Tilov, B., Markevych, I., and Dimitrova, D. (2017) "Residential road traffic noise and general mental health in youth: The role of noise annoyance, neighborhood restorative quality, physical activity, and social cohesion as potential mediators" Environment International 109 pp. 1-9.

Eagly, A. H., and Mladinic, A. (1994) "Are people prejudiced against women? Some answers from research on attitudes, gender stereotypes, and judgments of competence" European Review of Social Psychology 5 (1), pp. 1-35.

Eaton, A. A., Majka, E. A., and Visser, P. S. (2008) "Emerging perspectives on the structure and function of attitude strength" European Review of Social Psychology 19 (1), pp. 165-201.

Eberhardt, J. L., Strâle, L. O., and Berlin, M. H. (1987) "The influence of continuous and intermittent traffic noise on sleep" Journal of Sound and Vibration 116 (3), pp. 445-464.

Egan, T. M. (2002) "Grounded theory research and theory building" Advances in developing human resources 4 (3), pp. 277-295.

Ellermeier, W., Eigenstetter, M., and Zimmer, K. (2001) "Psychoacoustic correlates of individual noise sensitivity" Journal of the Acoustical Society of America 109 (4), pp. 1464-1473.

Ellis, D. (1993) "Modeling the information-seeking patterns of academic researchers – a grounded theory approach" Library Quarterly 63 (4), pp. 469-486.

Engle Merry, S. (1993) "Mending walls and building fences: Constructing the private neighborhood" Journal of Legal Pluralism and Unofficial Law 33 pp. 71-90.

Evans, G. W., Bullinger, M., and Hygge, S. (1998) "Chronic noise exposure and physiological response: A prospective study of children living under environmental stress" Psychological science 9 (1), pp. 75-77.

Evans, G. W., Lercher, P., and Kofler, W. W. (2002) "Crowding and children's mental health: The role of house type" Journal of Environmental Psychology 22 (3), pp. 221-231.

Evans, G. W., Lercher, P., Meis, M., Ising, H., and Kofler, W. W. (2001) "Community noise exposure and stress in children" Journal of the Acoustical Society of America 109 (3), pp. 1023-1027.

Fabrigar, L. R., MacDonald, T. K., and Wegener, D. T. (2005) "The structure of attitudes" in The handbook of attitudes, edited by Albarracín, D., Johnson, B. T., and Zanna, M. P. Taylor & Francis, pp. 79-124.

Farrell, S. J., Aubry, T., and Coulombe, D. (2004) "Neighborhoods and neighbors: Do they contribute to personal well-being?" Journal of community psychology 32 (1), pp. 9-25.

Faul, F., Erdfelder, E., Buchner, A., and Lang, A. G. (2009) "Statistical power analyses using G* Power 3.1: Tests for correlation and regression analyses" Behavior Research Methods 41 (4), pp. 1149-1160.

Faul, F., Erdfelder, E., Lang, A. G., and Buchner, A. (2007) "G* Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences" Behavior Research Methods 39 (2), pp. 175-191.

Fehr, B., and Russell, J. A. (1984) "Concept of emotion viewed from a prototype perspective" Journal of experimental psychology: general 113 (3), pp. 464-486.

Fidell, S., Silvati, L., and Pearsons, K. (1998) "Noticeability of a decrease in aircraft noise" Noise Control Engineering Journal 46 (2), pp. 49-56.

Fidell, S., Teffeteller, S., Horonjeff, R., and Green, D. M. (1979) "Predicting annoyance from detectability of low-level sounds" Journal of the Acoustical Society of America 66 (5), pp. 1427-1434.

Field, A. (2018) Discovering Statistics Using IBM SPSS Statistics, Sage.

Fields, J. M. (1984) "The effect of numbers of noise events on people’s reactions to noise: An analysis of existing survey data" Journal of the Acoustical Society of America 75 (2), pp. 447-467.

Fields, J. M. (1992) Effect of personal and situational variables on noise annoyance: With special reference to implications for en route noise. National Aeronautics and Space Administration (NASA).

Fields, J. M. (1993) "Effect of personal and situational variables on noise annoyance in residential areas" Journal of the Acoustical Society of America 93 (5), pp. 2753-2763.

Fields, J. M., de Jong, R. G., Gjestland, T., Flindell, I. H., Job, R. F. S., Kurra, S., Lercher, P., Vallet, M., Yano, T., Guski, R., Felscher-Suhr, U., and Schumer, R. (2001) "Standardized general-purpose noise reaction questions for community noise surveys: Research and a recommendation" Journal of Sound and Vibration 242 (4), pp. 641-679.

Floor Noise Management Centre (2018) Monthly report: May 2018. Floor Noise Management Centre, Korea Environment Corporation, Republic of Korea.

Fogarty, G. J., Machin, M. A., Albion, M. J., Sutherland, L. F., Lalor, G. I., and Revitt, S. (1999) "Predicting occupational strain and job satisfaction: The role of stress, coping, personality, and affectivity variables" Journal of Vocational Behavior 54 (3), pp. 429-452.

Folkman, S. (1997) "Positive psychological states and coping with severe stress" Social Science & Medicine 45 (8), pp. 1207-1221.

Folkman, S. (2013) "Stress: Appraisal and coping" in Encyclopedia of Behavioral Medicine, edited by Gellman, M. D., and Turner, J. R. Springer, pp. 1913-1915.

Folkman, S., and Lazarus, R. S. (1988) "The relationship between coping and emotion: Implications for theory and research" Social Science & Medicine 26 (3), pp. 309-317.

Fridlund, A. J., and Cacioppo, J. T. (1986) "Guidelines for human electromyographic research" Psychophysiology 23 (5), pp. 567-589.

Friedman, H. S., and Priebe, C. E. (1998) "Estimating stimulus response latency" Journal of Neuroscience Methods 83 (2), pp. 185-194.

Friedrichs, J., and Blasius, J. (2009) "Attitudes of owners and renters in a deprived neighbourhood" European Journal of Housing Policy 9 (4), pp. 435-455.

Fritz, H. (1958) The Psychology of Interpersonal Relations, Wiley.

Frontczak, M., Schiavon, S., Goins, J., Arens, E., Zhang, H., and Wargocki, P. (2012) "Quantitative relationships between occupant satisfaction and satisfaction aspects of indoor environmental quality and building design" Indoor Air 22 (2), pp. 119-131.

Fyhri, A., and Aasvang, G. M. (2010) "Noise, sleep and poor health: Modeling the relationship between road traffic noise and cardiovascular problems" Science of the Total Environment 408 (21), pp. 4935-4942.

Fyhri, A., and Klæboe, R. (2006) "Direct, indirect influences of income on road traffic noise annoyance" Journal of Environmental Psychology 26 (1), pp. 27-37.

Fyhri, A., and Klæboe, R. (2009) "Road traffic noise, sensitivity, annoyance and self-reported health: A structural equation model exercise" Environment International 35 (1), pp. 91-97.

Gass, S., and Neu, J. (2006) Speech Acts Across Cultures: Challenges to Communication in a Second Language, Walter de Gruyter.

Gerin, W., Davidson, K. W., Christenfeld, N. J., Goyal, T., and Schwartz, J. E. (2006) "The role of angry rumination and distraction in blood pressure recovery from emotional arousal" Psychosomatic Medicine 68 (1), pp. 64-72.

Gilam, G., and Hendler, T. (2016) "With love, from me to you: Embedding social interactions in affective neuroscience" Neuroscience & Biobehavioral Reviews 68 pp. 590-601.

Glaser, B. G., and Holton, J. (2004) "Remodeling grounded theory" Forum: Qualitative Social Research 5 (2).

Glaser, B. G., and Strauss, A. L. (1967) The Discovery of Grounded Theory: Strategies for Qualitative Research, Aldine.

Glaser, B. G., and Strauss, A. L. (2009) The Discovery of Grounded Theory: Strategies for Qualitative Research, Aldine.

Glass, D. C., and Singer, J. E. (1972) Urban Stress: Experiments on Noise and Social Stressors, Academic Press.

Goldstein, D. S., and Kopin, I. J. (2007) "Evolution of concepts of stress" Stress 10 (2), pp. 109-120.

Gomez, P., and Danuser, B. (2004) "Affective and physiological responses to environmental noises and music" International Journal of Psychophysiology 53 (2), pp. 91-103.

Gomez, P., Zimmermann, P., Guttormsen-Schär, S., and Danuser, B. (2005) "Respiratory responses associated with affective processing of film stimuli" Biological psychology 68 (3), pp. 223-235.

Good, K., and Roy, K. (2010) "An approach to making safe and secure indoor soundscape measurements" The Journal of the Acoustical Society of America 127 (3), pp. 1804-1804.

Götz, O., Liehr-Gobbers, K., and Krafft, M. (2010) "Evaluation of structural equation models using the partial least squares (PLS) approach" in Handbook of Partial Least Squares, edited by Vinzi, V. E., Chin, W. W., Henseler, J., and Wang, H. Springer, pp. 691-711.

Graham, F. K., and Clifton, R. K. (1966) "Heart-rate change as a component of the orienting response" Psychological bulletin 65 (5), pp. 305-320.

Greenwald, M. K., Cook, E. W., and Lang, P. J. (1989) "Affective judgment and psychophysiological response: Dimensional covariation in the evaluation of pictorial stimuli" Journal of Psychophysiology 3 (1), pp. 51-64.

Griefahn, B., Brode, P., Marks, A., and Basner, M. (2008) "Autonomic arousals related to traffic noise during sleep" SLEEP 31 (4), pp. 569-577.

Grimwood, C. J. (1993) "Effects on environmental noise on people at home" in Information Paper 22/93, Building Research Establishment (BRE), UK.

Grossmann, I., Ellsworth, P. C., and Hong, Y. Y. (2012) "Culture, attention, and emotion" Journal of experimental psychology: general 141 (1), pp. 31-36.

Groves, P. M., and Thompson, R. F. (1970) "Habituation: A dual-process theory" Psychological review 77 (5), pp. 419-450.

Guest, A. M., Kubrin, C. E., and Cover, J. K. (2008) "Heterogeneity and harmony: Neighbouring relationships among whites in ethnically diverse neighbourhoods in Seattle" Urban Studies 45 (3), pp. 501-526.

Guite, H., Clark, C., and Ackrill, G. (2006) "The impact of the physical and urban environment on mental well-being" Public health 120 (12), pp. 1117-1126.

Guski, R. (1997) "Psychological methods for evaluating sound quality and assessing acoustic information" Acta Acustica United with Acustica 83 (5), pp. 765-774.

Guski, R. (1999) "Personal and social variables as co-determinants of noise annoyance" Noise & Health 1 (3), pp. 45-56.

Guski, R., Felscher-Suhr, U., and Schuemer, R. (1999) "The concept of noise annoyance: How international experts see it" Journal of Sound and Vibration 223 (4), pp. 513-527.

Guski, R., Wichmann, U., Rohrmann, B., and Finke, H. O. (1978) Construction and application of a questionnaire for social scientific study of the effects of environmental noise (TM-75492). National Aeronautics and Space Administration (NASA).

Habarth, J. M., Graham-Bermann, S. A., and Bermann, E. A. (2009) "Coping in context: Community and natural resources in low-income women's environments" Environment and Behavior 41 (2), pp. 205-232.

Hahn, D. W., and Kang, H. J. (2000) "Appropriateness and frequency of emotion terms in Korea" Korean Journal of Psychology 19 (2), pp. 63-99.

Haines, M. M., Brentnall, S. L., Stansfeld, S. A., and Klineberg, E. (2003) "Qualitative responses of children to environmental noise" Noise & Health 5 (19), pp. 19-30.

Happ, M. B., and Kagan, S. H. (2001) "Methodological considerations for grounded theory research in critical care settings" Nursing Research 50 (3), pp. 188-192.

Harburg, E., Blakelock Jr, E. H., and Roeper, P. J. (1979) "Resentful and reflective coping with arbitrary authority and blood pressure: Detroit" Psychosomatic Medicine 41 (3), pp. 189-202.

Hari, R., Henriksson, L., Malinen, S., and Parkkonen, L. (2015) "Centrality of social interaction in human brain function" Neuron 88 (1), pp. 181-193.

Harmon-Jones, E., and Harmon-Jones, C. (2016) "Anger" in Handbook of emotions, edited by Feldman Barrett, L., Lewis, M., and Haviland-Jones, J. M. Guilford Press, pp. 774-791.

Harris, R. L. (2013) Experiencing the research role of the consultant radiographer: A grounded theory study, University of Exeter.

Hatfield, J., Job, R. F. S., Hede, A. J., Carter, N. L., Peploe, P., Taylor, R., and Morrell, S. (2002) "Human response to environmental noise: The role of perceived control" International Journal of Behavioral Medicine 9 (4), pp. 341-359.

Heinonen-Guzejev, M., Vuorinen, H. S., Mussalo-Rauhamaa, H., Heikkilä, K., Koskenvuo, M., and Kaprio, J. (2007) "The association of noise sensitivity with coronary heart and cardiovascular mortality among Finnish adults" Science of the Total Environment 372 (2), pp. 406-412.

Henry, D., Gorman-Smith, D., Schoeny, M., and Tolan, P. (2014) "“Neighborhood matters”: Assessment of neighborhood social processes" American journal of community psychology 54 (3-4), pp. 187-204.

Henwood, K., and Pidgeon, N. (2006) "Grounded theory" in Research methods in psychology, edited by Breakwell, G. M., Hammond, S., Fife-Schaw, C., and Smith, J. A. Sage, pp. 342-365.

Hickey, G. (1997) "The use of literature in grounded theory" Nursing Times Research 2 (5), pp. 371-378.

Higginson, R. J. (2007) Cardiac rehabilitation attendance and women: A Straussian grounded theory, University of Glamorgan.

Hirakawa, S., and Hopkins, C. (2018) "Experimental determination of transient structure-borne sound power from heavy impact sources on heavyweight floors with floating floors using an inverse form of transient statistical energy analysis" Applied Acoustics 140 pp. 74-82.

Hodges, S. D., Kiel, K. J., Kramer, A. D. I., Veach, D., and Villanueva, B. R. (2010) "Giving birth to empathy: The effects of similar experience on empathic accuracy, empathic concern, and perceived empathy" Personality and Social Psychology Bulletin 36 (3), pp. 398-409.

Holand, S., Girard, A., Laude, D., Meyer-Bisch, C., and Elghozi, J. L. (1999) "Effects of an auditory startle stimulus on blood pressure and heart rate in humans" Journal of hypertension 17 (12), pp. 1893-1897.

Hopkins, C. (2007) Sound insulation, Routledge.

Hopkins, C. (2015) "Revision of international standards on field measurements of airborne, impact and façade sound insulation to form the ISO 16283 series" Building and Environment 92 pp. 703-712.

Huang, E. H. C. (2014) "Field floor impact noise south-east Queensland (Australia)" in INTER-NOISE and NOISE-CON Congress and Conference, Melbourne, Australia.

Hume, K., and Ahtamad, M. (2013) "Physiological responses to and subjective estimates of soundscape elements" Applied Acoustics 74 (2), pp. 275-281.

Hume, K., Barrett, H., Ip, A., McDonagh, T., Davies, W., Adams, M., Bruce, N., Cain, R., Jennings, P., Czanner, G., Carlyle, A., Cusack, P., and Plack, C. (2008) "Physiological responses and subjective estimates of sounds: Initial results of pilot study" in Institute of Acoustics.

Hutchinson, S. A. (1993) "Grounded theory: The method" in Nursing Research: A Qualitative Perspective, edited by Munhall, P. L., and Boyd, C. O. National League for Nursing Press, pp. 180-212.

ISO 131:1979 (1979) Expression of physical and subjective magnitudes of sound or noise in air. International Organization for Standardization (ISO), Geneva, Switzerland.

ISO 9613-2 (1996) Acoustics – Attenuation of sound during propagation outdoors, Part 2: General method of calculation. International Organization for Standardization (ISO), Geneva, Switzerland.

ISO/TS 15666 (2003) Assessment of noise annoyance by means of social and socio-acoustic surveys. International Organization for Standardization (ISO), Geneva, Switzerland.

ISO 1996-2 (2007) Acoustics – Description, measurement and assessment of environmental noise, Part 2: Determination of environmental noise levels. International Organization for Standardization (ISO), Geneva, Switzerland.

ISO 10140-3 (2010a) Acoustics – Laboratory measurement of sound insulation of building elements, Part 3: Measurement of impact sound insulation. International Organization for Standardization (ISO), Geneva, Switzerland.

ISO 10140-5 (2010b) Acoustics – Laboratory measurement of sound insulation of building elements, Part 5: Requirements for test facilities and equipment. International Organization for Standardization (ISO), Geneva, Switzerland.

ISO 1996-2 (2017) Acoustics – Description, measurement and assessment of environmental noise, Part 2: Determination of environmental noise levels. International Organization for Standardization (ISO), Geneva, Switzerland.

ISO 16283-2 (2018) Acoustics – Field measurement of sound insulation in buildings and of building elements, Part 2: Impact sound insulation. International Organization for Standardization (ISO), Geneva, Switzerland.

Jackson, J. C. (1974) "Amplitude and habituation of the orienting reflex as a function of stimulus intensity" Psychophysiology 11 (6), pp. 647-659.

Jakovljević, B., Paunović, K., and Belojević, G. (2009) "Road-traffic noise and factors influencing noise annoyance in an urban population" Environment International 35 (3), pp. 552-556.

JIS A 1418-2 (2000) Acoustics – Measurement of floor impact sound insulation of buildings. Part 2: Method using standard heavy impact sources. Japanese Industrial Standards Committee, Tokyo, Japan.

Jelínková, Z. (1988) "Coping with noise in noise sensitive subjects" in International congress on noise as a public health problem, ICBEN, Stockholm, Sweden.

Jennings, J. R., and Gianaros, P. J. (2007) "Methodology" in Handbook of psychophysiology, edited by Cacioppo, J. T., Tassinary, L. G., and Berntson, G. G. Cambridge University Press, pp. 812-833.

Jeon, J. Y., Hong, J. Y., Kim, S. M., and Lee, P. J. (2015) "Classification of heavy-weight floor impact sounds in multi-dwelling houses using an equal-appearing interval scale" Building and Environment 94 pp. 821-828.

Jeon, J. Y., Jeong, J. H., Vorländer, M., and Thaden, R. (2004) "Evaluation of floor impact sound insulation in reinforced concrete buildings" Acta Acustica United with Acustica 90 (2), pp. 313-318.

Jeon, J. Y., Lee, P. J., Kim, J. H., and Yoo, S. Y. (2009a) "Subjective evaluation of heavy-weight floor impact sounds in relation to spatial characteristics" Journal of the Acoustical Society of America 125 (5), pp. 2987-2994.

Jeon, J. Y., Lee, P. J., and Sato, S. (2009b) "Use of the standard rubber ball as an impact source with heavyweight concrete floors" Journal of the Acoustical Society of America 126 (1), pp. 167-178.

Jeon, J. Y., Lee, P. J., You, J., and Kang, J. (2010a) "Perceptual assessment of quality of urban soundscapes with combined noise sources and water sounds" Journal of the Acoustical Society of America 127 (3), pp. 1357-1366.

Jeon, J. Y., Ryu, J. K., Jeong, J. H., and Tachibana, H. (2006a) "Review of the impact ball in evaluating floor impact sound" Acta Acustica United with Acustica 92 (5), pp. 777-786.

Jeon, J. Y., Ryu, J. K., and Lee, P. J. (2010b) "A quantification model of overall dissatisfaction with indoor noise environment in residential buildings" Applied Acoustics 71 (10), pp. 914-921.

Jeon, J. Y., Yoo, S. Y., Jeong, Y., and Jeong, J. H. (2006b) "The effect of the design elements of reinforced concrete slab on heavy-weight floor impact noise" Journal of the Architectural Institute of Korea: Planning & Design 22 (10), pp. 329-336.

Jeon, J. Y., You, J., and Chang, H. Y. (2007) "Sound radiation and sound quality characteristics of refrigerator noise in real living environments" Applied Acoustics 68 (10), pp. 1118-1134.

Jeon, J. Y., You, J., Lee, P. J., and Kang, J. (2008) "Evaluation of soundscapes in open public spaces" in INTER-NOISE and NOISE-CON Congress and Conference, Shanghai, China.

Job, R. F. S. (1988) "Community response to noise: A review of factors influencing the relationship between noise exposure and reaction" Journal of the Acoustical Society of America 83 (3), pp. 991-1001.

Jones, M., and Alony, I. (2011) "Guiding the use of grounded theory in doctoral studies–an example from the Australian film industry" International Journal of Doctoral Studies 6 pp. 95-114.

Kaiser, L. (1989) "Adjusting for baseline: Change or percentage change?" Statistics in medicine 8 (10), pp. 1183-1190.

Kang, J. (2006) Urban Sound Environment, CRC Press.

Kearney, M. H., Murphy, S., and Rosenbaum, M. (1994) "Mothering on crack cocaine: A grounded theory analysis" Social Science & Medicine 38 (2), pp. 351-361.

Keen, S. (2006) "A theory of narrative empathy" Narrative 14 (3), pp. 207-236.

Kessler, R. C., Price, R. H., and Wortman, C. B. (1985) "Social factors in psychopathology: Stress, social support, and coping processes" Annual review of psychology 36 (1), pp. 531-572.

Kim, J., and Kaplan, R. (2004) "Physical and psychological factors in sense of community: New urbanist Kentlands and nearby Orchard Village" Environment and Behavior 36 (3), pp. 313-340.

Kimura, S. (1996) "Development of floor impact sound insulation technology in Japan" Journal of the Acoustical Society of America 100 (4), pp. 2768-2768.

Knipschild, P. (1977) "V. Medical effects of aircraft noise: Community cardiovascular survey" International Archives of Occupational and Environmental Health 40 (3), pp. 185-190.

KS F 2810-2 (2012) Field measurements of floor impact sound insulation of buildings, Part 2: Method using standard heavy impact sources. Korean Standards Committee, Seoul, Republic of Korea.

Kristal-Boneh, E., Melamed, S., Harari, G., and Green, M. S. (1995) "Acute and chronic effects of noise exposure on blood pressure and heart rate among industrial employees: The Cordis Study" Archives of Environmental Health: An International Journal 50 (4), pp. 298-304.

Kroesen, M., Molin, E. J., and van Wee, B. (2008) "Testing a theory of aircraft noise annoyance: A structural equation analysis" Journal of the Acoustical Society of America 123 (6), pp. 4250-4260.

Kryter, K. D. (1970) The Effects of Noise on Man, Academic Press.

Kurra, S., Morimoto, M., and Maekawa, Z. I. (1999) "Transportation noise annoyance: A simulated-environment study for road, railway and aircraft noises, Part 1: Overall annoyance" Journal of Sound and Vibration 220 (2), pp. 251-278.

Lai, A. C. K., Mui, K. W., Wong, L. T., and Law, L. Y. (2009) "An evaluation model for indoor environmental quality (IEQ) acceptance in residential buildings" Energy and Buildings 41 (9), pp. 930-936.

Lai, J. H., and Yik, F. W. (2009) "Perception of importance and performance of the indoor environmental quality of high-rise residential buildings" Building and Environment 44 (2), pp. 352-360.

Lang, P. J., Bradley, M. M., and Cuthbert, B. N. (1997) "Motivated attention: Affect, activation, and action" in Attention and orienting: Sensory and motivational processes, edited by Lang, P. J., Simons, R. F., and Balaban, M. T. Lawrence Erlbaum Associates, pp. 97-135.

Langdon, F. J., Buller, I. B., and Scholes, W. E. (1981) "Noise from neighbors and the sound insulation of party walls in houses" Journal of Sound and Vibration 79 (2), pp. 205-228.

Larsen, R. J., and Diener, E. (1992) "Promises and problems with the circumplex model of emotion" in Review of Personality and Social Psychology, No. 13. Emotion, edited by Clark, M. S. Sage, pp. 25-59.

Laszlo, H. E., McRobie, E. S., Stansfeld, S. A., and Hansell, A. L. (2012) "Annoyance and other reaction measures to changes in noise exposure: A review" Science of the Total Environment 435-436 pp. 551-562.

Latack, J. C., and Havlovic, S. J. (1992) "Coping with job stress: A conceptual evaluation framework for coping measures" Journal of organizational behavior 13 (5), pp. 479-508.

Lazarus, R. S. (1966) Psychological Stress and the Coping Process, McGraw-Hill.

Lazarus, R. S. (1991) Emotion and Adaptation, Oxford University Press.

Lazarus, R. S. (1993) "From psychological stress to the emotions: A history of changing outlooks" Annual review of psychology 44 (1), pp. 1-21.

Lazarus, R. S., and Folkman, S. (1984) Stress, Appraisal, and Coping, Springer.

Lee, P. J. (2010) "An investigation of floor impact sources and perception models of impact sounds" Journal of the Acoustical Society of America 128 (1), pp. 506-506.

Lee, P. J., and Griffin, M. J. (2013) "Combined effect of noise and vibration produced by high-speed trains on annoyance in buildings" Journal of the Acoustical Society of America 133 (4), pp. 2126-2135.

Lee, P. J., and Jeon, J. Y. (2008) "Soundwalk for evaluating community noise annoyance in urban spaces" in International congress on noise as a public health problem, ICBEN, Foxwoods, Connecticut.

Lee, P. J., and Jeon, J. Y. (2011) "Evaluation of speech transmission in open public spaces affected by combined noises" Journal of the Acoustical Society of America 130 (1), pp. 219-227.

Lee, P. J., and Jeon, J. Y. (2013) "Relating traffic, construction, and ventilation noise to cognitive performances and subjective perceptions" Journal of the Acoustical Society of America 134 (4), pp. 2765-2772.

Lee, P. J., Kim, J. H., and Jeon, J. Y. (2009) "Psychoacoustical characteristics of impact ball sounds on concrete floors" Acta Acustica United with Acustica 95 (4), pp. 707-717.

Lee, P. J., Kim, Y. H., Jeon, J. Y., and Song, K. D. (2007) "Effects of apartment building façade and balcony design on the reduction of exterior noise" Building and Environment 42 (10), pp. 3517-3528.

Lee, P. J., Lee, B. K., and Griffin, M. J. (2013) "Evaluation of floor vibrations induced by walking in reinforced concrete buildings" in INTER-NOISE and NOISE-CON Congress and Conference, Innsbruck, Austria.

Lee, P. J., Lee, B. K., Jeon, J. Y., Zhang, M., and Kang, J. (2014) "Effect of noise disturbance on job satisfaction and health symptoms in open-plan offices: A structural equation model exercise" in Forum Acusticum, Kraków, Poland.

Lee, P. J., and Park, S. H. (2015) Development of conceptual model of floor impact sound through socio-acoustic approach. Korea Institute of Construction Technology (KICT), Republic of Korea.

Lee, P. J., Shim, M. H., and Jeon, J. Y. (2010) "Effects of different noise combinations on sleep, as assessed by a general questionnaire" Applied Acoustics 71 (9), pp. 870-875.

Lee, S. C., Lee, P. J., and Jeon, J. Y. (2012) "Assessment of annoyance caused by different types of construction noises" Journal of the Acoustical Society of America 131 (4), pp. 3502-3502.

Lee, S. W. (2004) "Impact Sound Insulation Characteristics of Floors according to the number of P'yong and Layers" The International Journal of The Korea Institute of Ecological Architecture and Environment 4 (3), pp. 71-78.

Lee, S. Y., Song, X. Y., Skevington, S., and Hao, Y. T. (2005) "Application of structural equation models to quality of life" Structural Equation Modeling: A Multidisciplinary Journal 12 (3), pp. 435-453.

Lee, W. C., Lim, M. H., Paik, K. C., Kim, H. W., Kim, H. D., Kim, H. J., Rho, S. C., and Kwon, H. J. (2008) "Expose to chronic aircraft noise and emotion, behavior characteristics in Korean children" Korean Journal of Aerospace and environmental Medicine 18 (2), pp. 42-49.

Leonard, S. (1973) "A causal model for relating noise exposure, psychosocial variables and aircraft noise annoyance" in International congress on noise as a public health problem, ICBEN, Dubrovnik, Yugoslavia.

Lercher, P. (1996) "Environmental noise and health: An integrated research perspective" Environment International 22 (1), pp. 117-129.

Lercher, P. (2003) "Which health outcomes should be measured in health related environmental quality of life studies?" Landscape and Urban Planning 65 (1–2), pp. 63-72.

Lercher, P., Botteldooren, D., Widmann, U., Uhrner, U., and Kammeringer, E. (2011) "Cardiovascular effects of environmental noise: Research in Austria" Noise & Health 13 (52), pp. 234-250.

Lercher, P., Evans, G. W., Meis, M., and Kofler, W. W. (2002) "Ambient neighbourhood noise and children's mental health" Occupational and Environmental Medicine 59 (6), pp. 380-386.

Lercher, P., and Kofler, W. W. (1996) "Behavioral and health responses associated with road traffic noise exposure along alpine through-traffic routes" Science of the Total Environment 189 pp. 85-89.

Levy-Leboyer, C., and Naturel, V. (1991) "Neighbourhood noise annoyance" Journal of Environmental Psychology 11 (1), pp. 75-86.

Lewis, M. (1993) "The development of anger and rage" in The Role of Affect in Motivation, Development, and Adaptation, Vol. 2. Rage, Power, and Aggression, edited by Glick, R. A., and Roose, S. P. Yale University Press, pp. 148-168.

Lindborg, P. (2013) "Physiological measures regress onto acoustic and perceptual features of soundscapes" in International Conference on Music & Emotion, ICME, Jyväskylä, Finland.

Little, J. W., and Mabry, J. E. (1969) "Sound duration and its effect on judged annoyance" Journal of Sound and Vibration 9 (2), pp. 247-262.

Liu, F., and Kang, J. (2016) "A grounded theory approach to the subjective understanding of urban soundscape in Sheffield" Cities 50 pp. 28-39.

Ljunggren, F., Simmons, C., and Hagberg, K. (2014) "Correlation between sound insulation and occupants' perception: Proposal of alternative single number rating of impact sound" Applied Acoustics 85 pp. 57-68.

Ljunggren, F., Simmons, C., and Öqvist, R. (2017) "Correlation between sound insulation and occupants' perception: Proposal of alternative single number rating of impact sound, Part 2" Applied Acoustics 123 pp. 143-151.

Loughran, L. E. (2011) Qualitative exploration of recovery following first episode psychosis: A grounded theory approach & clinical research portfolio, University of Glasgow.

Luyben, J. G. (2008) Mothering the mother: A study of effective content of routine care during pregnancy from women's points of view in three European countries, Glasgow Caledonian University.

Mabbott, L. a. (2012) Therapeutic interpretations of psychodynamis ideas: A social constructionist grounded theory, Roehampton University.

Maris, E., Stallen, P. J., Vermunt, R., and Steensma, H. (2007) "Noise within the social context: Anoyance reduction through fair procedures" Journal of the Acoustical Society of America 121 (4), pp. 2000-2010.

Marzbali, M. H., Abdullah, A., Razak, N. A., and Tilaki, M. J. M. (2012) "The influence of crime prevention through environmental design on victimisation and fear of crime" Journal of Environmental Psychology 32 (2), pp. 79-88.

Maschke, C., and Niemann, H. (2007) "Health effects of annoyance induced by neighbour noise" Noise Control Engineering Journal 55 (3), pp. 348-356.

Matsumoto, D., Keltner, D., Shiota, M. N., O'Sullivan, M., and Frank, M. (2008) "Facial expressions of emotion" in Handbook of emotions, edited by Lewis, M., Haviland-Jones, J. M., and Feldman Barrett, L. The Guilford Press, pp. 211-234.

Matthews, G., Campbell, S. E., Falconer, S., Joyner, L. A., Huggins, J., Gilliland, K., Grier, R., and Warm, J. S. (2002) "Fundamental dimensions of subjective state in performance settings: Task engagement, distress, and worry" Emotion 2 (4), pp. 315-340.

Maziul, M., Job, R. F. S., and Vogt, J. (2005) "Complaint data as an index of annoyance – theoretical and methodological issues" Noise & Health 7 (28), pp. 17-27.

McCann, T. V., and Clark, E. (2004a) "Grounded theory in nursing research, Part 1: Methodology" Nurse Researcher 11 (2), pp. 7-18.

McCann, T. V., and Clark, E. (2004b) "Grounded theory in nursing research, Part 2: Critique" Nurse Researcher 11 (2), pp. 19-28.

McCann, T. V., and Clark, E. (2004c) "Grounded theory in nursing research, Part 3: Application" Nurse Researcher 11 (2), pp. 29-39.

McElhinney, R. (2008) Professional identity development: A grounded theory study of clinical psychology trainees, University of Edinburgh.

McFarlane, H. M. (2014) Experiences of sickness absence among NHS staff: A grounded theory analysis, University of the West of England, Bristol.

McGahan, P. (1972) "The neighbor role and neighboring in a highly urban area" Sociological Quarterly 13 (3), pp. 397-408.

McGhee, G., and Atkinson, J. (2010) "The carer/key worker relationship cycle: A theory of the reciprocal process" Journal of psychiatric and mental health nursing 17 (4), pp. 312-318.

McGhee, G., Marland, G. R., and Atkinson, J. (2007) "Grounded theory research: Literature reviewing and reflexivity" Journal of Advanced Nursing 60 (3), pp. 334-342.

McHorney, C. A., Ware Jr, J. E., Lu, J. R., and Sherbourne, C. D. (1994) "The MOS 36-item short-form health survey (SF-36): III. Tests of data quality, scaling assumptions, and reliability across diverse patient groups" Medical care pp. 40-66.

McHorney, C. A., Ware Jr, J. E., and Raczek, A. E. (1993) "The MOS 36-Item short-form health survey (SF-36): II. Psychometric and clinical tests of validity in measuring physical and mental health constructs" Medical care pp. 247-263.

Meegan, R., and Mitchell, A. (2001) "'It's not community round here, it's neighbourhood': Neighbourhood change and cohesion in urban regeneration policies" Urban Studies 38 (12), pp. 2167-2194.

Miedema, H. M. E. (2004) "Relationship between exposure to multiple noise sources and noise annoyance" Journal of the Acoustical Society of America 116 (2), pp. 949-957.

Miedema, H. M. E., and Vos, H. (1998) "Exposure-response relationships for transportation noise" Journal of the Acoustical Society of America 104 (6), pp. 3432-3445.

Miedema, H. M. E., and Vos, H. (1999) "Demographic and attitudinal factors that modify annoyance from transportation noise" Journal of the Acoustical Society of America 105 (6), pp. 3336-3344.

Miedema, H. M. E., and Vos, H. (2004) "Noise annoyance from stationary sources: Relationships with exposure metric day-evening-night level (DENL) and their confidence intervals" Journal of the Acoustical Society of America 116 (1), pp. 334-343.

Ministry of Construction and Transportation (2005) Criteria on the authorization and management of block structures for floor impact sounds in multi-dwelling houses. Republic of Korea.

Ministry of Land, Infrastructure and Transport (2018) Presidential decree for the regulations on housing construction standards, etc. (No. 28243). Republic of Korea.

Morgan, C. T., King, R. A., and Robinson, N. M. (1979) Introduction to Psychology, McGraw-Hill.

Namba, S., Kuwano, S., Hashimoto, T., Berglund, B., Da Rui, Z., Schick, A., Hoege, H., and Florentine, M. (1991) "Verbal expression of emotional impression of sound" Journal of the Acoustical Society of Japan 12 (1), pp. 19-29.

Nasar, J. L., and Julian, D. A. (1995) "The Psychological Sense of Community in the Neighborhood" Journal of the American Planning Association 61 (2), pp. 178-184.

Neubauer, R. O., and Kang, J. (2014) "Airborne sound insulation in terms of a loudness model" Applied Acoustics 85 pp. 34-45.

Nijland, H. A., Hartemink, S., van Kamp, I., and van Wee, B. (2007) "The influence of sensitivity for road traffic noise on residential location: Does it trigger a process of spatial selection?" Journal of the Acoustical Society of America 122 (3), pp. 1595-1601.

Nivison, M. E., and Endresen, I. M. (1993) "An analysis of relationships among environmental noise, annoyance and sensitivity to noise, and the consequences for health and sleep" Journal of behavioral medicine 16 (3), pp. 257-276.

Nykaza, E. T., Hodgdon, K. K., Gaugler, T., Krecker, P., and Luz, G. A. (2013) "On the relationship between blast noise complaints and community annoyance" Journal of the Acoustical Society of America 133 (5), pp. 2690-2698.

Öhman, A., and Soares, J. J. F. (1994) "Unconscious anxiety: Phobic responses to masked stimuli" Journal of abnormal psychology 103 (2), pp. 231-240.

Öhrström, E. (1995) "Effects of low-levels of road traffic noise during the night: A laboratory study on number of events, maximum noise-levels and noise sensitivity" Journal of Sound and Vibration 179 (4), pp. 603-615.

Öhrström, E., Barregård, L., Andersson, E., Skånberg, A., Svensson, H., and Ängerheim, P. (2007) "Annoyance due to single and combined sound exposure from railway and road traffic" Journal of the Acoustical Society of America 122 (5), pp. 2642-2652.

Öhrström, E., and Björkman, M. (1988) "Effects of noise-disturbed sleep: A laboratory study on habituation and subjective noise sensitivity" Journal of Sound and Vibration 122 (2), pp. 277-290.

Öhrström, E., Björkman, M., and Rylander, R. (1980) "Laboratory annoyance and different traffic noise sources" Journal of Sound and Vibration 70 (3), pp. 333-341.

Öhrström, E., Björkman, M., and Rylander, R. (1988) "Noise annoyance with regard to neurophysiological sensitivity, subjective noise sensitivity and personality-variables" Psychological Medicine 18 (3), pp. 605-613.

Öhrström, E., and Rylander, R. (1982) "Sleep disturbance effects of traffic noise: A laboratory study on after effects" Journal of Sound and Vibration 84 (1), pp. 87-103.

Öhrström, E., and Rylander, R. (1990) "Sleep disturbance by road traffic noise: A laboratory study on number of noise events" Journal of Sound and Vibration 143 (1), pp. 93-101.

Okokon, E. O., Turunen, A. W., Ung-Lanki, S., Vartiainen, A.-K., Tiittanen, P., and Lanki, T. (2015) "Road-traffic noise: Annoyance, risk perception, and noise sensitivity in the Finnish adult population" International Journal of Environmental Research and Public Health 12 (6), pp. 5712-5734.

Oliver, R. L. (1977) "Effect of expectation and disconfirmation on postexposure product evaluations: An alternative interpretation" Journal of applied psychology 62 (4), p. 480.

Ortony, A., Clore, G. L., and Foss, M. A. (1987) "The referential structure of the affective lexicon" Cognitive science 11 (3), pp. 341-364.

Ouis, D. (2001) "Annoyance from road traffic noise: A review" Journal of Environmental Psychology 21 (1), pp. 101-120.

Pandit, N. R. (1996) "The creation of theory: A recent application of the grounded theory method" The qualitative report 2 (4), pp. 1-15.

Paquin, G. W., and Gambrill, E. (1994) "The problem with neighbors" Journal of community psychology 22 (1), pp. 21-32.

Park, H. S., Oh, B. K., Kim, Y., and Cho, T. (2015) "Low-frequency impact sound transmission of floating floor: Case study of mortar bed on concrete slab with continuous interlayer" Building and Environment 94 pp. 793-801.

Park, I. J., and Min, K. H. (2005) "Making a list of Korean emotion terms and exploring dimensions underlying them" Korean Journal of Social and Personality Psychology 19 (1), pp. 109-129.

Park, K. H. (2015a) "Criminal study on the noise: Focused on the floor impact noise dispute" Inha Law Review 18 (3), pp. 297-328.

Park, S. H. (2015b) Understanding the perception of floor impact sounds in apartment buildings, Acoustics Research Unit, School of Architecture, University of Liverpool, UK.

Park, S. H., Lee, P. J., and Yang, K. S. (2016a) "Perception and reaction to floor impact noise in apartment buildings: A qualitative approach" Acta Acustica United with Acustica 102 (5), pp. 902-911.

Park, S. H., Lee, P. J., Yang, K. S., and Kim, K. W. (2016b) "Relationships between non-acoustic factors and subjective reactions to floor impact noise in apartment buildings" Journal of the Acoustical Society of America 139 (3), pp. 1158-1167.

Parrot, J., Petiot, J. C., Lobreau, J. P., and Smolik, H. J. (1992) "Cardiovascular effects of impulse noise, road traffic noise, and intermittent pink noise at LAeq= 75 dB, as a function of sex, age, and level of anxiety: A comparative study" International Archives of Occupational and Environmental Health 63 (7), pp. 477-484.

Paunović, K., Jakovljević, B., and Belojević, G. (2009) "Predictors of noise annoyance in noisy and quiet urban streets" Science of the Total Environment 407 (12), pp. 3707-3711.

Pedersen, E., Hallberg, L. R. M., and Persson Waye, K. (2007) "Living in the vicinity of wind turbines – A grounded theory study" Qualitative Research in Psychology 4 (1-2), pp. 49-63.

Pedersen, E., and Persson Waye, K. (2004) "Perception and annoyance due to wind turbine noise – A dose-response relationship" Journal of the Acoustical Society of America 116 (6), pp. 3460-3470.

Pedersen, E., and Persson Waye, K. (2007) "Wind turbine noise, annoyance and self-reported health and well-being in different living environments" Occupational and Environmental Medicine 64 (7), pp. 480-486.

Pedersen, E., van den Berg, F., Bakker, R., and Bouma, J. (2009) "Response to noise from modern wind farms in The Netherlands" Journal of the Acoustical Society of America 126 (2), pp. 634-643.

Pennig, S., and Schady, A. (2014) "Railway noise annoyance: Exposure-response relationships and testing a theoretical model by structural equation analysis" Noise & Health 16 (73), pp. 388-399.

Persson Waye, K. (2004) "Effects of low frequency noise on sleep" Noise & Health 6 (23), pp. 87-91.

Persson Waye, K., Bengtsson, J., Kjellberg, A., and Benton, S. (2001) "Low frequency noise "pollution" interferes with performance" Noise & Health 4 (13), pp. 33-49.

Persson Waye, K., Bengtsson, J., Rylander, R., Hucklebridge, F., Evans, P., and Clow, A. (2002) "Low frequency noise enhances cortisol among noise sensitive subjects during work performance" Life sciences 70 (7), pp. 745-758.

Pierrette, M., Marquis-Favre, C., Morel, J., Rioux, L., Vallet, M., Viollon, S., and Moch, A. (2012) "Noise annoyance from industrial and road traffic combined noises: A survey and a total annoyance model comparison" Journal of Environmental Psychology 32 (2), pp. 178-186.

Potter, G. G., Hartman, M., and Ward, T. (2009) "Perceived stress and everyday memory complaints among older adult women" Anxiety, Stress & Coping 22 (4), pp. 475-481.

Poulsen, T. (1991) "Influence of session length on judged annoyance" Journal of Sound and Vibration 145 (2), pp. 217-224.

Poulton, E. C. (1978) "A new look at the effects of noise: A rejoinder" Psychological bulletin 85 (5), pp. 1068-1079.

Power, E. R. (2015) "Placing community self-governance: Building materialities, nuisance noise and neighbouring in self-governing communities" Urban Studies 52 (2), pp. 245-260.

Pujol, S., Berthillier, M., Defrance, J., Lardiès, J., Petit, R., Houot, H., Levain, J. P., Masselot, C., and Mauny, F. (2012) "Urban ambient outdoor and indoor noise exposure at home: A population-based study on schoolchildren" Applied Acoustics 73 (8), pp. 741-750.

Rahim, M. A. (1986) "Referent role and styles of handling interpersonal conflict" Journal of Social Psychology 126 (1), pp. 79-86.

Rasmussen, B., and Rindel, J. H. (2010) "Sound insulation between dwellings – Descriptors applied in building regulations in Europe" Applied Acoustics 71 (3), pp. 171-180.

Rechavi, T. B. (2009) "A room for living: Private and public aspects in the experience of the living room" Journal of Environmental Psychology 29 (1), pp. 133-143.

Regecová, V., and Kellerová, E. (1995) "Effects of urban noise pollution on blood pressure and heart rate in preschool children" Journal of hypertension 13 (4), pp. 405-412.

Reinhardt, T., Schmahl, C., Wüst, S., and Bohus, M. (2012) "Salivary cortisol, heart rate, electrodermal activity and subjective stress responses to the Mannheim Multicomponent Stress Test (MMST)" Psychiatry Research 198 (1), pp. 106-111.

Rice, C. G. (1996) "Human response effects of impulse noise" Journal of Sound and Vibration 190 (3), pp. 525-543.

Robinson, M., and Hopkins, C. (2015) "Prediction of maximum fast time-weighted sound pressure levels due to transient excitation from the rubber ball and human footsteps" Building and Environment 94 pp. 810-820.

Rodon, J., and Pastor, J. A. (2007) "Applying grounded theory to study the implementation of an inter-organizational information system" Electronic Journal of Business Research Methods 5 (2), pp. 71-82.

Rollwagen, H. (2016) "The relationship between dwelling type and fear of crime" Environment and Behavior 48 (2), pp. 365-387.

Roseman, I. J. (1991) "Appraisal determinants of discrete emotions" Cognition and emotion 5 (3), pp. 161-200.

Roseman, I. J., Spindel, M. S., and Jose, P. E. (1990) "Appraisals of emotion-eliciting events: Testing a theory of discrete emotions" Journal of Personality and Social Psychology 59 (5), pp. 899-915.

Russell, J. A. (1980) "A circumplex model of affect" Journal of Personality and Social Psychology 39 (6), pp. 1161-1178.

Rylander, R., Björkman, M., Åhrlin, U., Sörensen, S., and Berglund, K. (1980) "Aircraft noise annoyance contours: Importance of overflight frequency and noise level" Journal of Sound and Vibration 69 (4), pp. 583-595.

Ryu, J. K., and Jeon, J. Y. (2011) "Influence of noise sensitivity on annoyance of indoor and outdoor noises in residential buildings" Applied Acoustics 72 (6), pp. 336-340.

Ryu, J. K., Sato, H., Kurakata, K., Hiramitsu, A., Tanaka, M., and Hirota, T. (2011) "Relation between annoyance and single-number quantities for rating heavy-weight floor impact sound insulation in wooden houses" Journal of the Acoustical Society of America 129 (5), pp. 3047-3055.

Sawada, Y. (1993) "Reproducible increases in blood pressure during intermittent noise exposure: Underlying haemodynamic mechanisms specific to passive coping" European journal of applied physiology and occupational physiology 67 (4), pp. 367-374.

Scherer, K. R. (2001) "Appraisal considered as a process of multilevel sequential checking" in Appraisal processes in emotion: Theory, methods, research, edited by Scherer, K. R., Schorr, A., and Johnstone, T. Oxford University Press, pp. 92-120.

Schmidt, B., Warns, L., Hellmer, M., Ulrich, N., and Hewig, J. (2018) "What makes us feel good or bad" Journal of Individual Differences 39 pp. 142-150.

Schneider, R., Schmidt, S., Binder, M., Schäfer, F., and Walach, H. (2003) "Respiration-related artifacts in EDA recordings: Introducing a standardized method to overcome multiple interpretations" Psychological reports 93 (3), pp. 907-920.

Schomer, P. D., and Wagner, L. R. (1996) "On the contribution of noticeability of environmental sounds to noise annoyance" Noise Control Engineering Journal 44 (6), pp. 294-305.

Schreckenberg, D. (2008) "The association between residential quality of life and aircraft noise annoyance around Frankfurt Airport" in Acoustics '08 Paris, Paris, France.

Schreckenberg, D., Benz, S., Belke, C., Möhler, U., and Guski, R. (2017) "The relationship between aircraft sound levels, noise annoyance and mental well-being: An analysis of moderated mediation" in International congress on noise as a public health problem, ICBEN, Zurich, Switzerland.

Schreckenberg, D., Griefahn, B., and Meis, M. (2010) "The associations between noise sensitivity, reported physical and mental health, perceived environmental quality, and noise annoyance" Noise & Health 12 (46), pp. 7-16.

Schulte-Fortkamp, B., and Fiebig, A. (2006) "Soundscape analysis in a residential area: An evaluation of noise and people's mind" Acta Acustica United with Acustica 92 (6), pp. 875-880.

Schultz, T. J. (1978) "Synthesis of social surveys on noise annoyance" Journal of the Acoustical Society of America 64 (2), pp. 377-405.

Seik, F. T. (2001) "Planning and design of Tampines, an award-winning high-rise, high-density township in Singapore" Cities 18 (1), pp. 33-42.

Selye, H. (1936) "A syndrome produced by diverse nocuous agents" Nature 138 (3479), p. 32.

Selye, H. (1956) The Stress of Life, McGraw-Hill.

Shaver, P., Schwartz, J., Kirson, D., and O'connor, C. (1987) "Emotion knowledge: Further exploration of a prototype approach" Journal of Personality and Social Psychology 52 (6), pp. 1061-1086.

Shaw, J. B., Fields, M. W., Thacker, J. W., and Fisher, C. D. (1993) "The availability of personal and external coping resources: Their impact on job stress and employee attitudes during organizational restructuring" Work & Stress 7 (3), pp. 229-246.

Shepherd, D., Welch, D., Dirks, K. N., and Mathews, R. (2010) "Exploring the relationship between noise sensitivity, annoyance and health-related quality of life in a sample of adults exposed to environmental noise" International Journal of Environmental Research and Public Health 7 (10), pp. 3579-3594.

Skinner, C. (2002) The 1999/2000 National Survey of Attitudes to Environmental Noise – Volume 3 United Kingdom Results. Building Research Establishment (BRE), UK.

Skinner, E. A., Edge, K., Altman, J., and Sherwood, H. (2003) "Searching for the structure of coping: A review and critique of category systems for classifying ways of coping" Psychological bulletin 129 (2), pp. 216-269.

Skjæveland, O., Gärling, T., and Mæland, J. G. (1996) "A multidimensional measure of neighboring" American journal of community psychology 24 (3), pp. 413-435.

Smith, K., and Biley, F. (1997) "Understanding grounded theory principles and evaluation" Nurse Researcher 4 (3), pp. 17-30.

Smith, M. G., Croy, I., Ögren, M., and Persson Waye, K. (2013) "On the influence of freight trains on humans: A laboratory investigation of the impact of nocturnal low frequency vibration and noise on sleep and heart rate" Plos One 8 (2).

Sneddon, M., Pearsons, K., and Fidell, S. (2003) "Laboratory study of the noticeability and annoyance of low signal-to-noise ratio sounds" Noise Control Engineering Journal 51 (5), pp. 300-305.

Sohn, S. J., Park, M. S., Park, J. E., and Sohn, J. H. (2012) "Korean emotion vocabulary: Extraction and categorization of feeling words" Science of Emotion and Sensibility 15 (1), pp. 105-120.

Stallen, P. J. (1999) "A theoretical framework for environmental noise annoyance" Noise & Health 1 (3), pp. 69-79.

Stansfeld, S. A. (1992) "Noise, noise sensitivity and psychiatric disorder: Epidemiological and psychophysiological studies" Psychological medicine. Monograph supplement 22 pp. 1-44.

Stansfeld, S. A., Berglund, B., Clark, C., Lopez-Barrio, I., Fischer, P., Öhrström, E., Haines, M. M., Head, J., Hygge, S., van Kamp, I., and Berry, B. F. (2005) "Aircraft and road traffic noise and children's cognition and health: A cross-national study" The Lancet 365 (9475), pp. 1942-1949.

Stansfeld, S. A., Haines, M., and Brown, B. (2000) "Noise and health in the urban environment" Reviews on environmental health 15 (1-2), pp. 43-82.

Stansfeld, S. A., and Matheson, M. P. (2003) "Noise pollution: Non-auditory effects on health" British medical bulletin 68 (1), pp. 243-257.

Stansfeld, S. A., Sharp, D. S., Gallacher, J., and Babisch, W. (1993) "Road traffic noise, noise sensitivity and psychological disorder" Psychological Medicine 23 (4), pp. 977-985.

Staples, S. L., Cornelius, R. R., and Gibbs, M. S. (1999) "Noise disturbance from a developing airport: Perceived risk or general annoyance?" Environment and Behavior 31 (5), pp. 692-710.

Statistics Korea (2017) Complete enumeration results of the 2016 population and housing census. Statistics Korea, Republic of Korea.

Stern, P. N. (1980) "Grounded theory methodology: Its uses and processes" Image 12 (1), pp. 20-23.

Stevens, S. S. (1972) Psychophysics and Social Scaling, General Learning Press.

Stokoe, E., and Hepburn, A. (2005) "'You can hear a lot through the walls': Noise formulations in neighbour complaints" Discourse & Society 16 (5), pp. 647-673.

Strauss, A., and Corbin, J. (1990) Basics of Qualitative Research: Grounded Theory Procedures and Techniques, Sage.

Strauss, A., and Corbin, J. (1994) "Grounded theory methodology" in Handbook of qualitative research, edited by Denzin, N. K., and Lincoln, Y. S. Sage, pp. 273-285.

Strauss, A., and Corbin, J. (1998) Basics of Qualitative Research: Techniques and Procedures for Developing Grounded Theory, Sage.

Tajadura-Jiménez, A., Larsson, P., Väljamäe, A., Västfjäll, D., and Kleiner, M. (2010) "When room size matters: Acoustic influences on emotional responses to sounds" Emotion 10 (3), pp. 416-422.

Talen, E. (1999) "Sense of community and neighbourhood form: An assessment of the social doctrine of new urbanism" Urban Studies 36 (8), pp. 1361-1379.

Tassinary, L. G., Cacioppo, J. T., and Vanman, E. J. (2007) "The skeletomotor system: Surface electromyography" in Handbook of psychophysiology, edited by Cacioppo, J. T., Tassinary, L. G., and Berntson, G. G. Cambridge University Press, pp. 267-299.

The Korea Herald (2013) "Neighbors' noise disputes end in murder, arson" [online] Available at: http://www.koreaherald.com/view.php?ud=20130212000721 [Accessed 24 July, 2016]

Thomson, O. P., Petty, N. J., and Scholes, J. (2013) "Grounding osteopathic research – introducing grounded theory" International Journal of Osteopathic Medicine 17 (3), pp. 167-186.

Turchet, L., Moffat, D., Tajadura-Jiménez, A., Reiss, J. D., and Stockman, T. (2016) "What do your footsteps sound like? An investigation on interactive footstep sounds adjustment" Applied Acoustics 111 pp. 77-85.

Unger, D. G., and Wandersman, A. (1985) "The importance of neighbors: The social, cognitive, and affective components of neighboring" American journal of community psychology 13 (2), pp. 139-169.

Vallet, M., Gagneux, J. M., Blanchet, V., Favre, B., and Labiale, G. (1983) "Long-term sleep disturbance due to traffic noise" Journal of Sound and Vibration 90 (2), pp. 173-191.

van Dijk, F. J. H., Souman, A. M., and de Vries, F. F. (1987) "Non-auditory effects of noise in industry: VI. A final field study in industry" International Archives of Occupational and Environmental Health 59 (2), pp. 133-145.

van Dongen, J. E. F. (2001) "Noise Annoyance from Neighbours and the impact of sound insulation and other factors" in INTER-NOISE and NOISE-CON Congress and Conference, Hague, Netherlands.

van Kamp, I. (1990) Coping with noise and its health consequences, University of Groningen.

van Kamp, I., Job, R. F. S., Hatfield, J., Haines, M., Stellato, R. K., and Stansfeld, S. A. (2004) "The role of noise sensitivity in the noise-response relation: A comparison of three international airport studies" Journal of the Acoustical Society of America 116 (6), pp. 3471-3479.

van Kamp, I., Klaeboe, R., Brown, A. L., and Lercher, P. (2016a) "Soundscapes, human restoration, and quality of life" in Soundscape and the Built Environment, edited by Kang, J., and Schulte-Fortkamp, B. CRC Press, pp. 43-68.

van Kamp, I., Klæboe, R., Kruize, H., Brown, A. L., and Lercher, P. (2016b) "Soundscapes, human restoration and quality of life" in INTER-NOISE and NOISE-CON Congress and Conference, Hamburg, Germany.

van Kempen, E., van Kamp, I., Fischer, P., Davies, H., Houthuijs, D., Stellato, R., Clark, C., and Stansfeld, S. (2006) "Noise exposure and children's blood pressure and heart rate: The RANCH project" Occupational and Environmental Medicine 63 (9), pp. 632-639.

van Kleef, G. A., de Dreu, C. K. W., and Manstead, A. S. R. (2010) "An interpersonal approach to emotion in social decision making: The emotions as social information model" in Advances in Experimental Social Psychology, Academic Press, pp. 45-96.

van Kleef, G. A., van Doorn, E. A., Heerdink, M. W., and Koning, L. F. (2011) "Emotion is for influence" European Review of Social Psychology 22 (1), pp. 114-163.

Västfjäll, D. (2002) "Influences of current mood and noise sensitivity on judgments of noise annoyance" Journal of Psychology 136 (4), pp. 357-370.

Versfeld, N. J., and Vos, J. (1997) "Annoyance caused by sounds of wheeled and tracked vehicles" Journal of the Acoustical Society of America 101 (5), pp. 2677-2685.

Volkema, R. J., and Bergmann, T. J. (1995) "Conflict styles as indicators of behavioral patterns in interpersonal conflicts" Journal of Social Psychology 135 (1), pp. 5-15.

Vos, J. (2003) "A- and C-weighted sound levels as predictors of the annoyance caused by shooting sounds, for various façade attenuation types" Journal of the Acoustical Society of America 113 (1), pp. 336-347.

Wallenius, M. A. (2004) "The interaction of noise stress and personal project stress on subjective health" Journal of Environmental Psychology 24 (2), pp. 167-177.

Wang, C., Si, Y., Abdul-Rahman, H., and Wood, L. C. (2015) "Noise annoyance and loudness: Acoustic performance of residential buildings in tropics" Building Services Engineering Research and Technology 36 (6), pp. 680-700.

Ware Jr, J. E., and Sherbourne, C. D. (1992) "The MOS 36-item short-form health survey (SF-36): I. Conceptual framework and item selection" Medical care pp. 473-483.

Watson, D., Clark, L. A., and Tellegen, A. (1984) "Cross-cultural convergence in the structure of mood: A Japanese replication and a comparison with US findings" Journal of Personality and Social Psychology 47 (1), pp. 127-144.

Watson, D., and Tellegen, A. (1985) "Toward a consensual structure of mood" Psychological bulletin 98 (2), pp. 219-235.

Watson, J. P., Gaind, R., and Marks, I. M. (1972) "Physiological habituation to continuous phobic stimulation" Behaviour Research and Therapy 10 (3), pp. 269-278.

Watson, R. (2013) Reaching breaking point: A constructivist grounded theory of service users' understanding of crisis, Cardiff University.

Weinstein, N. D. (1978) "Individual differences in reactions to noise: A longitudinal study in a college dormitory" Journal of applied psychology 63 (4), pp. 458-466.

Wiener, C. (2007) "Making teams work in conducting grounded theory" in The Sage handbook of grounded theory, edited by Bryant, A., and Charmaz, K. Sage, pp. 293-310.

Wilson, H. S., and Hutchinson, S. A. (1996) "Methodologic mistakes in grounded theory" Nursing Research 45 (2), pp. 122-124.

Wispé, L. (1986) "The distinction between sympathy and empathy: To call forth a concept, a word is needed" Journal of Personality and Social Psychology 50 (2), pp. 314-321.

Wood, L., Frank, L. D., and Giles-Corti, B. (2010) "Sense of community and its relationship with walking and neighborhood design" Social Science & Medicine 70 (9), pp. 1381-1390.

World Health Organization (2018) "Environmental Noise Guidelines for the European Region" World Health Organization (WHO).

Yang, W., and Kang, J. (2005) "Acoustic comfort evaluation in urban open public spaces" Applied Acoustics 66 (2), pp. 211-229.

Yeon, J. O., Kim, K. W., and Yang, K. S. (2017) "A correlation between a single number quantity and noise level of real impact sources for floor impact sound" Applied Acoustics 125 pp. 20-33.

Yorukoglu, P. N. D., and Kang, J. (2016) "Analysing sound environment and architectural characteristics of libraries through indoor soundscape framework" Archives of acoustics 41 (2), pp. 203-212.

Yu, L., and Kang, J. (2008) "Effects of social, demographical and behavioral factors on the sound level evaluation in urban open spaces" Journal of the Acoustical Society of America 123 (2), pp. 772-783.

Zahr, L. K., and de Traversay, J. (1994) "Premature infant responses to noise reduction by earmuffs: Effects on behavioral and physiologic measures" Journal of Perinatology 15 (6), pp. 448-455.

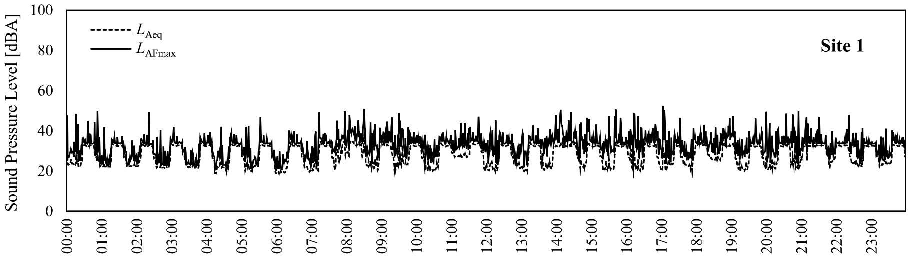
Zaki, J., and Ochsner, K. (2016) "Empathy" in Handbook of emotions, edited by Feldman Barrett, L., Lewis, M., and Haviland-Jones, J. M. Guilford Press, pp. 871-884.

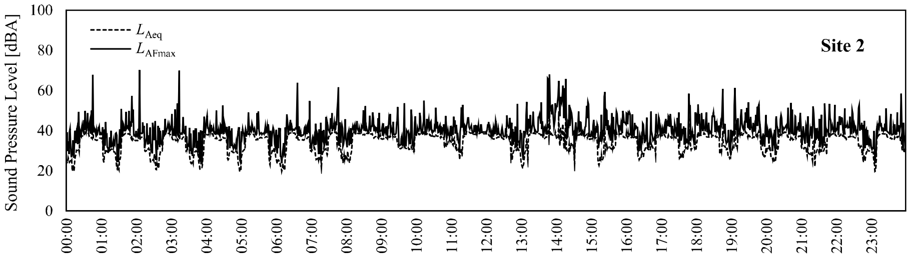
Zhang, Y., Kang, J., and Jin, H. (2015) "An experimental study on the restorative experience of typical urban soundscape based on EDA" in International Congress on Sound and Vibration, ICSV, Florence, Italy.

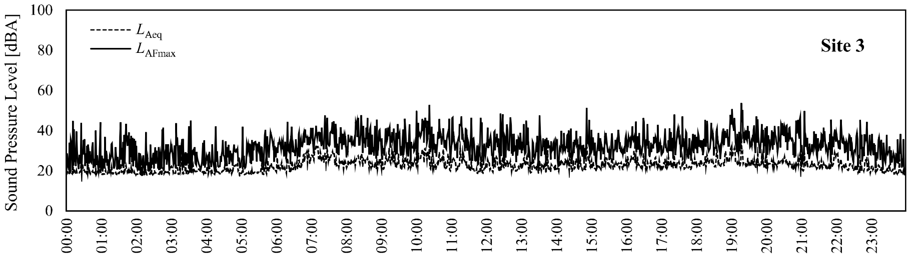
Appendices

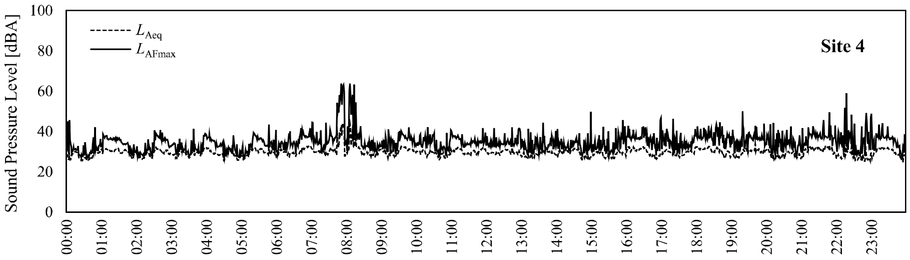
Appendix 1	Time histories of noise levels at each site (Chapter 3)
Appendix 2	Pictures of the laboratory study in Chapter 4
Appendix 3	Pictures of the laboratory study in Chapter 5
Appendix 4	Pictures of the online surveys in Chapter 6
Appendix 5	Pictures of the field study in Chapter 7
Appendix 6	Information about each interviewee and sample interview excerpts in which conditions were implied (Chapter 8)
Appendix 7	Published papers in peer-reviewed journals and conference proceedings

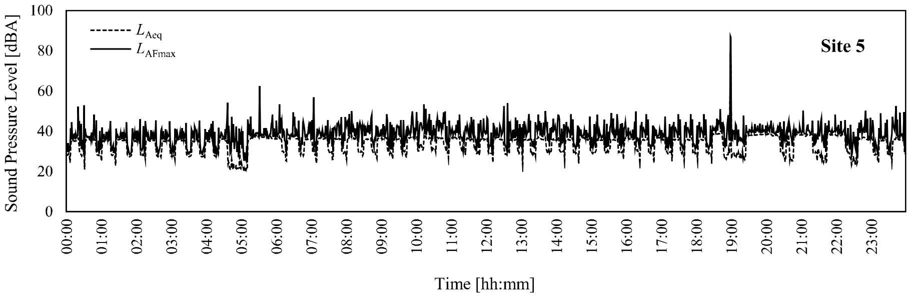
Appendix 1 Time histories of noise levels at each site (Chapter 3)

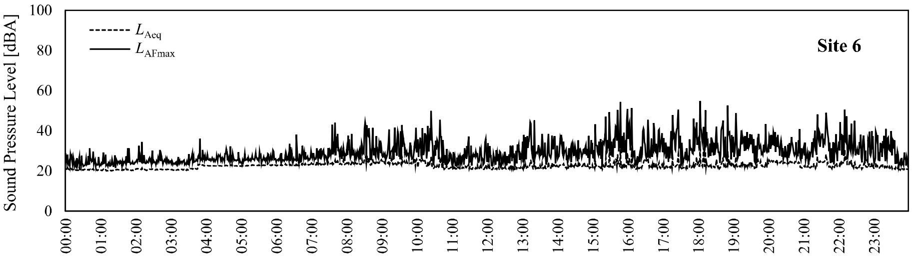


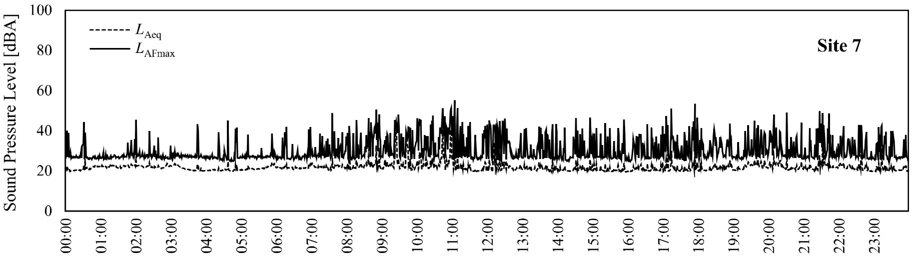


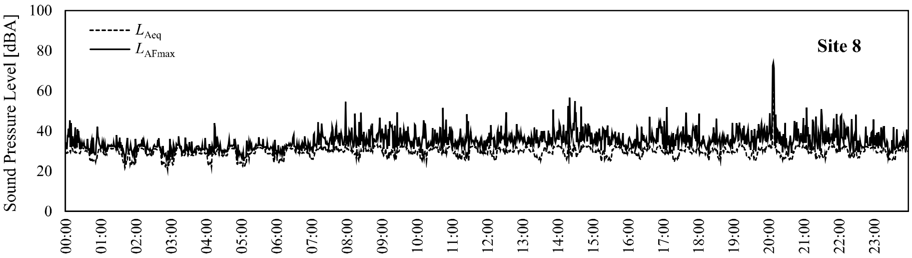


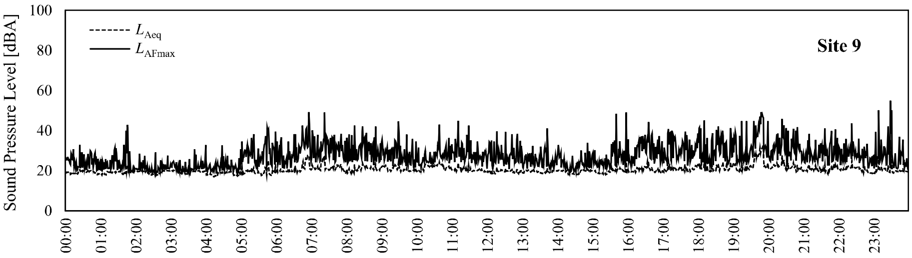


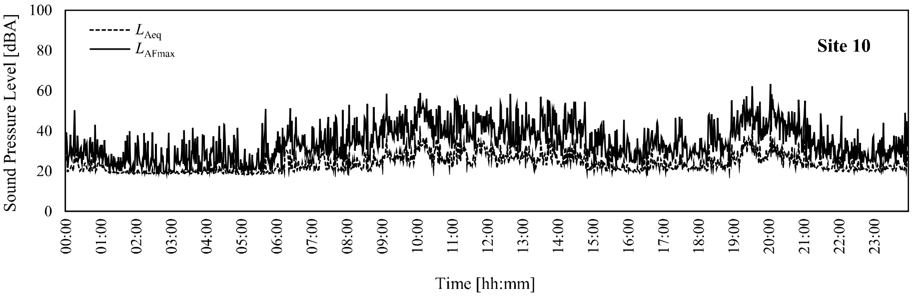


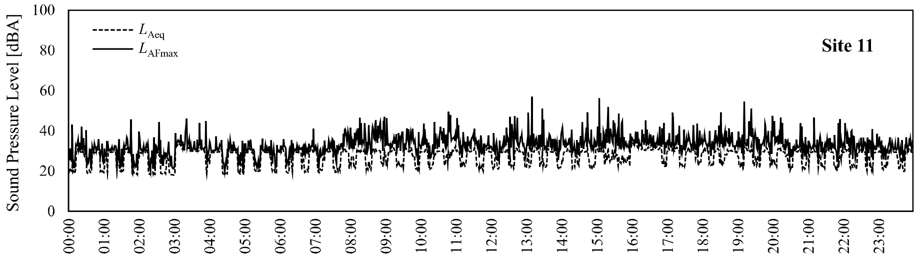

Site 6
L_{Aeq}
L_{AFmax}
Sound Pressure Level [dBA]
0
20
40
60
80
100
00:00
01:00
02:00
03:00
04:00
05:00
06:00
07:00
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00

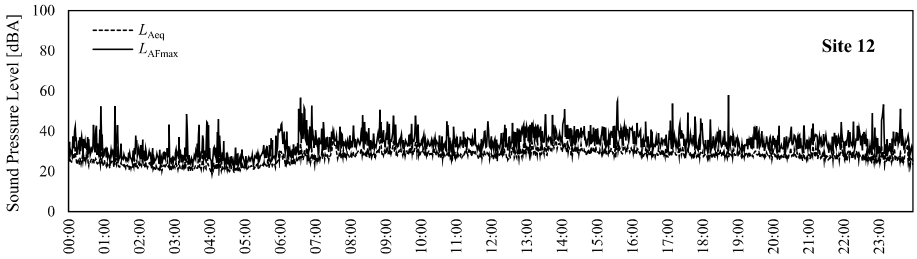

Site 7
L_{Aeq}
L_{AFmax}
Sound Pressure Level [dBA]
0
20
40
60
80
100
00:00
01:00
02:00
03:00
04:00
05:00
06:00
07:00
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00

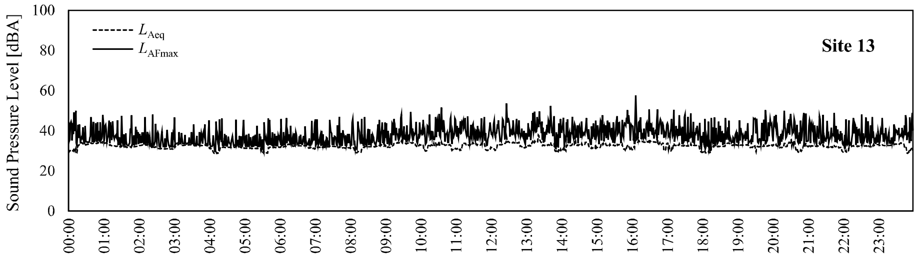

Site 8
L_{Aeq}
L_{AFmax}
Sound Pressure Level [dBA]
0
20
40
60
80
100
00:00
01:00
02:00
03:00
04:00
05:00
06:00
07:00
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00

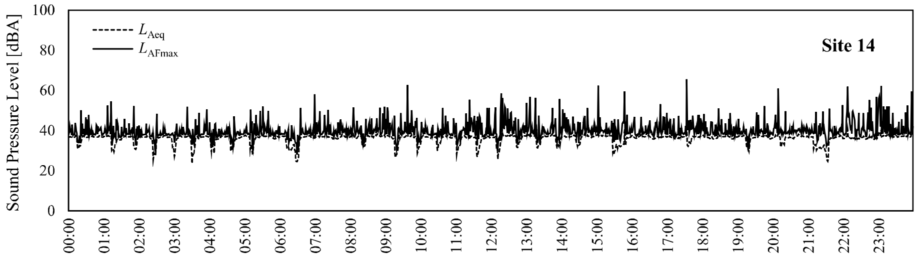

Site 9
L_{Aeq}
L_{AFmax}
Sound Pressure Level [dBA]
0
20
40
60
80
100
00:00
01:00
02:00
03:00
04:00
05:00
06:00
07:00
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00

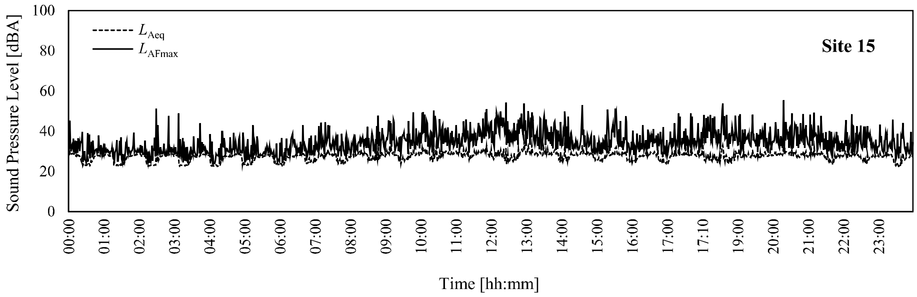

Site 10
L_{Aeq}
L_{AFmax}
Sound Pressure Level [dBA]
0
20
40
60
80
100
00:00
01:00
02:00
03:00
04:00
05:00
06:00
07:00
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00
Time [hh:mm]

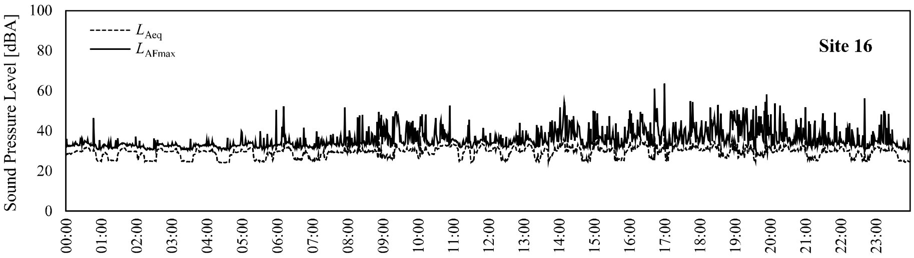

Sound Pressure Level [dBA]
100
80
60
40
20
0
L_{Aeq}
L_{AFmax}
Site 11
00:00
01:00
02:00
03:00
04:00
05:00
06:00
07:00
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00

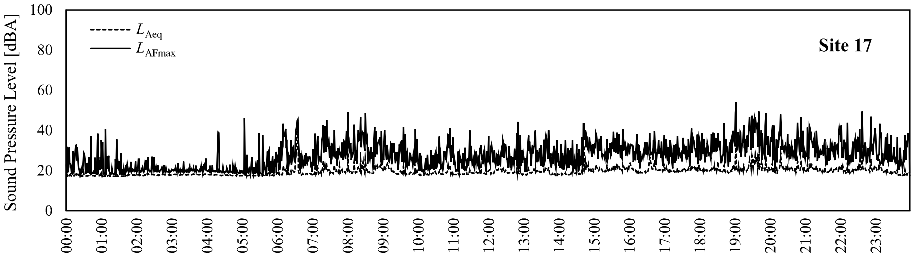

Sound Pressure Level [dBA]
100
80
60
40
20
0
L_{Aeq}
L_{AFmax}
Site 12
00:00
01:00
02:00
03:00
04:00
05:00
06:00
07:00
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00

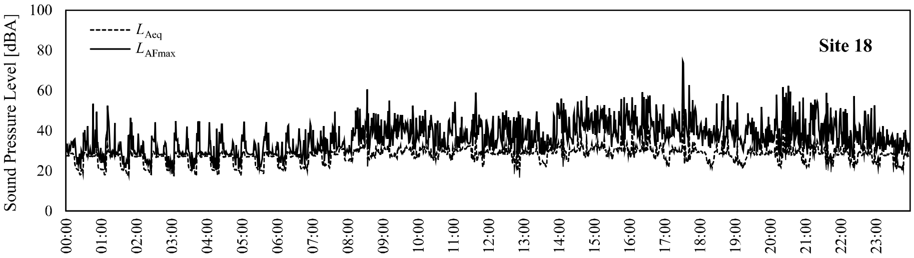

Sound Pressure Level [dBA]
100
80
60
40
20
0
L_{Aeq}
L_{AFmax}
Site 13
00:00
01:00
02:00
03:00
04:00
05:00
06:00
07:00
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00

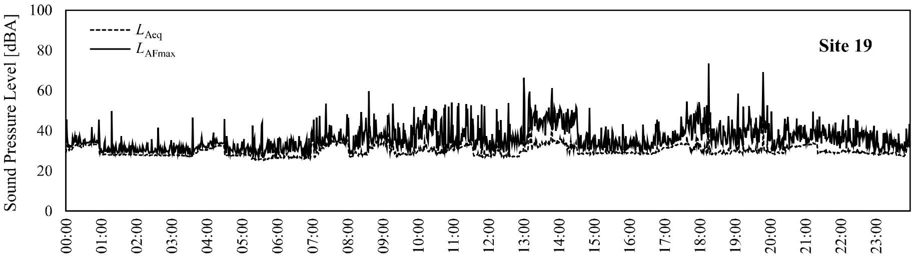

Sound Pressure Level [dBA]
100
80
60
40
20
0
L_{Aeq}
L_{AFmax}
Site 14
00:00
01:00
02:00
03:00
04:00
05:00
06:00
07:00
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00

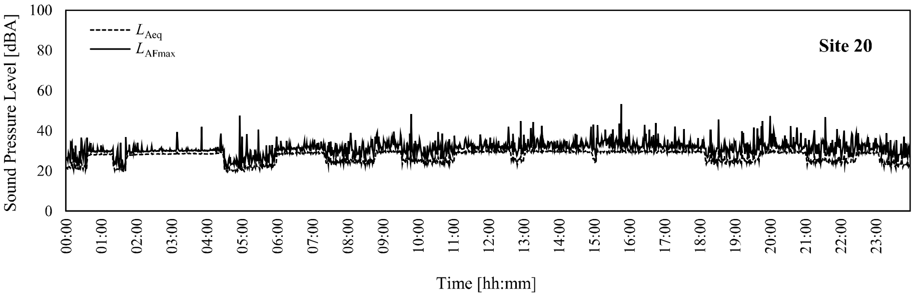

Sound Pressure Level [dBA]
100
80
60
40
20
0
L_{Aeq}
L_{AFmax}
Site 15
00:00
01:00
02:00
03:00
04:00
05:00
06:00
07:00
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
17:10
19:00
20:00
21:00
22:00
23:00
Time [hh:mm]

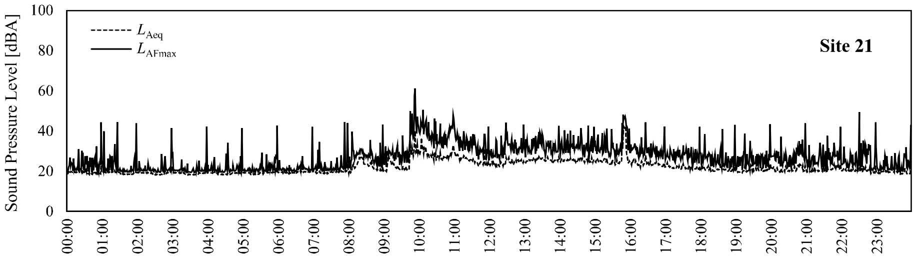

Site 16
L_{Aeq}
L_{AFmax}
Sound Pressure Level [dBA]
0
20
40
60
80
100
00:00
01:00
02:00
03:00
04:00
05:00
06:00
07:00
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00

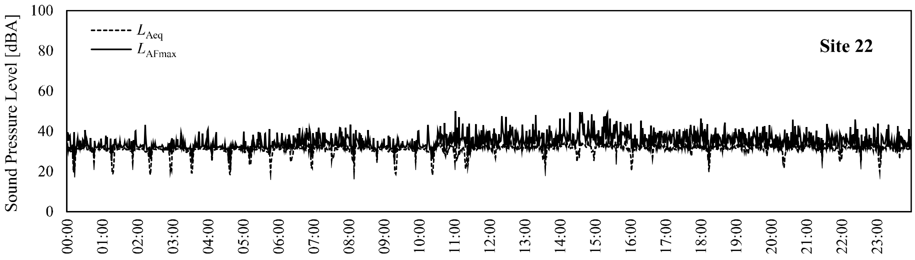

Site 17
L_{Aeq}
L_{AFmax}
Sound Pressure Level [dBA]
0
20
40
60
80
100
00:00
01:00
02:00
03:00
04:00
05:00
06:00
07:00
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00

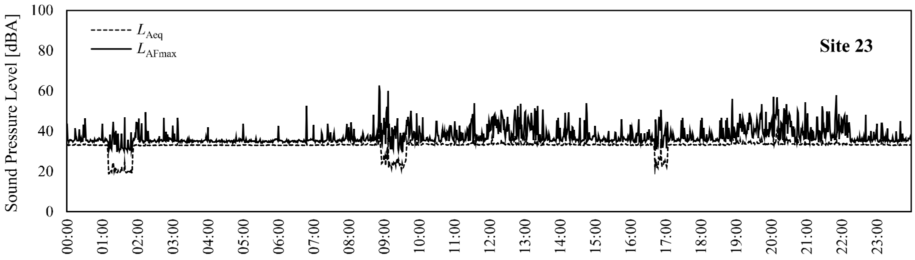

Site 18
L_{Aeq}
L_{AFmax}
Sound Pressure Level [dBA]
0
20
40
60
80
100
00:00
01:00
02:00
03:00
04:00
05:00
06:00
07:00
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00

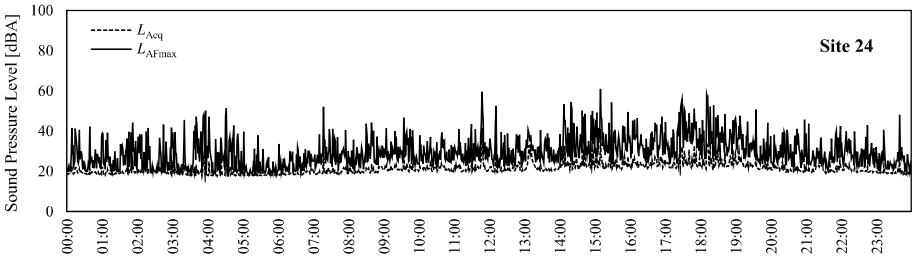

Site 19
L_{Aeq}
L_{AFmax}
Sound Pressure Level [dBA]
0
20
40
60
80
100
00:00
01:00
02:00
03:00
04:00
05:00
06:00
07:00
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00

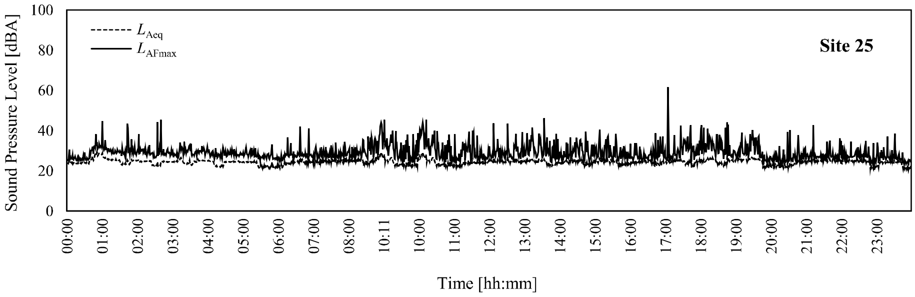

Site 20
L_{Aeq}
L_{AFmax}
Sound Pressure Level [dBA]
0
20
40
60
80
100
00:00
01:00
02:00
03:00
04:00
05:00
06:00
07:00
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00
Time [hh:mm]

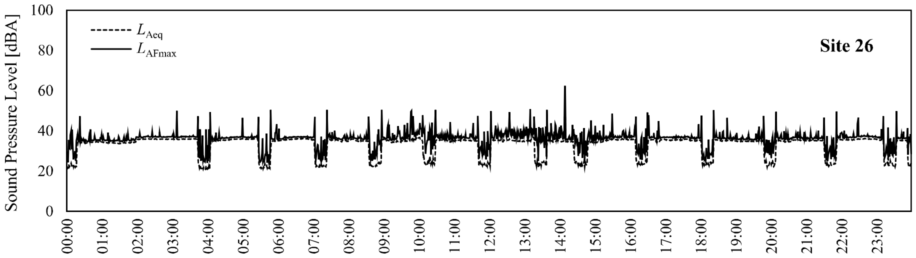

Sound Pressure Level [dBA]
100
80
60
40
20
0
L_{Aeq}
L_{AFmax}
Site 21
00:00
01:00
02:00
03:00
04:00
05:00
06:00
07:00
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00

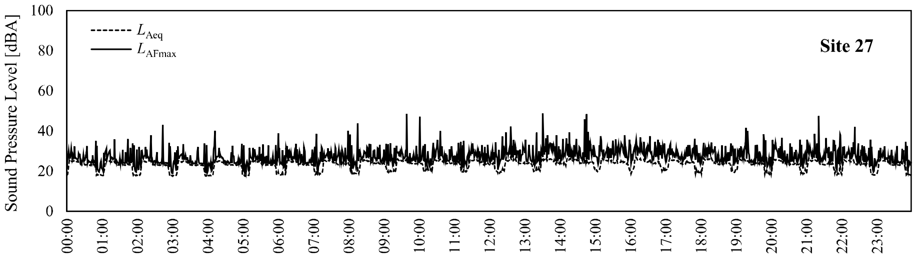

Sound Pressure Level [dBA]
100
80
60
40
20
0
L_{Aeq}
L_{AFmax}
Site 22
00:00
01:00
02:00
03:00
04:00
05:00
06:00
07:00
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00

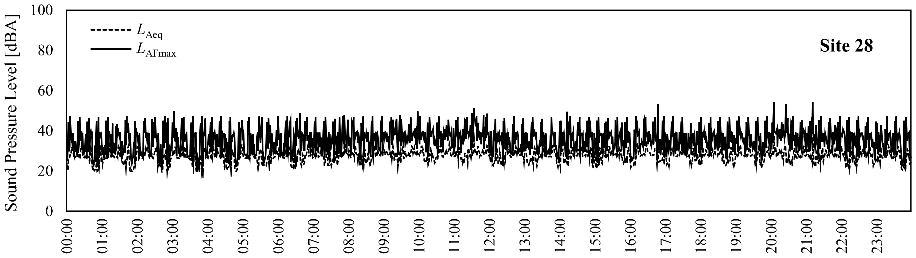

Sound Pressure Level [dBA]
100
80
60
40
20
0
L_{Aeq}
L_{AFmax}
Site 23
00:00
01:00
02:00
03:00
04:00
05:00
06:00
07:00
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00

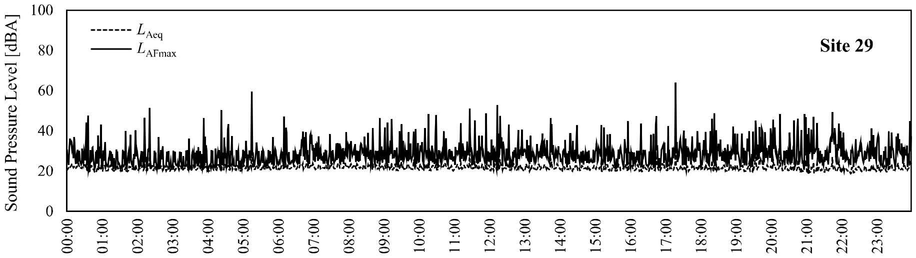

Sound Pressure Level [dBA]
100
80
60
40
20
0
L_{Aeq}
L_{AFmax}
Site 24
00:00
01:00
02:00
03:00
04:00
05:00
06:00
07:00
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00

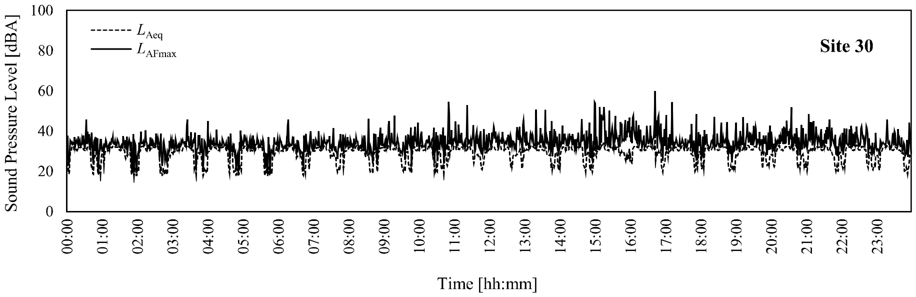

Sound Pressure Level [dBA]
100
80
60
40
20
0
L_{Aeq}
L_{AFmax}
Site 25
00:00
01:00
02:00
03:00
04:00
05:00
06:00
07:00
08:00
10:11
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00
Time [hh:mm]

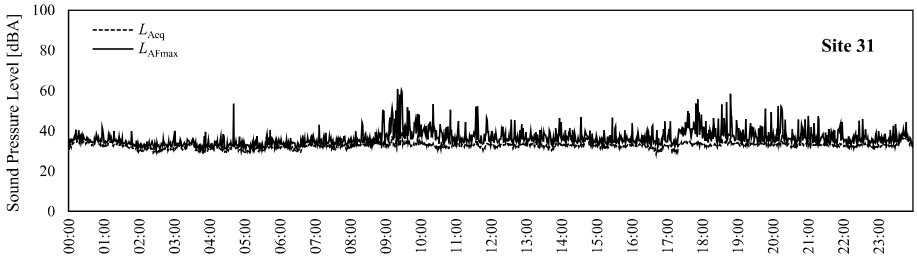

Sound Pressure Level [dBA]
0
20
40
60
80
100
L_{Aeq}
L_{AFmax}
Site 26
00:00
01:00
02:00
03:00
04:00
05:00
06:00
07:00
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00

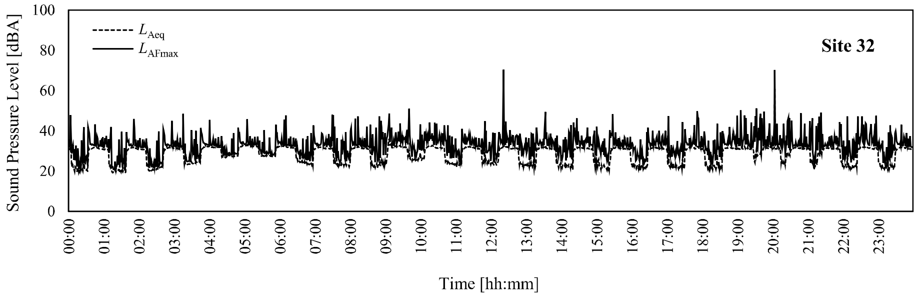

Sound Pressure Level [dBA]
0
20
40
60
80
100
L_{Aeq}
L_{AFmax}
Site 27
00:00
01:00
02:00
03:00
04:00
05:00
06:00
07:00
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00


Sound Pressure Level [dBA]
0
20
40
60
80
100
L_{Aeq}
L_{AFmax}
Site 28
00:00
01:00
02:00
03:00
04:00
05:00
06:00
07:00
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00


Sound Pressure Level [dBA]
0
20
40
60
80
100
L_{Aeq}
L_{AFmax}
Site 29
00:00
01:00
02:00
03:00
04:00
05:00
06:00
07:00
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00


Sound Pressure Level [dBA]
0
20
40
60
80
100
L_{Aeq}
L_{AFmax}
Site 30
00:00
01:00
02:00
03:00
04:00
05:00
06:00
07:00
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00
Time [hh:mm]


Sound Pressure Level [dBA]
100
80
60
40
20
0
L_{Aeq}
L_{AFmax}
Site 31
00:00
01:00
02:00
03:00
04:00
05:00
06:00
07:00
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00


Sound Pressure Level [dBA]
100
80
60
40
20
0
L_{Aeq}
L_{AFmax}
Site 32
00:00
01:00
02:00
03:00
04:00
05:00
06:00
07:00
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00
Time [hh:mm]

Appendix 2 Pictures of the laboratory study in Chapter 4

Figure A2-1. Noise sources in the source room (upstairs): an impact ball (top left), a chair (top right), a toy (bottom left), and a child (bottom right).

Figure A2-2. A head and torso simulator located in the receiving room (downstairs).

Figure A2-3. Outside of the audiometric booth: computers for stimuli presentation and data acquisition.

Figure A2-4. Electrodes were attached to the participant; the participant was seated in the audiometric booth and the loudspeakers were located in front of the participant.

Appendix 3 Pictures of the laboratory study in Chapter 5

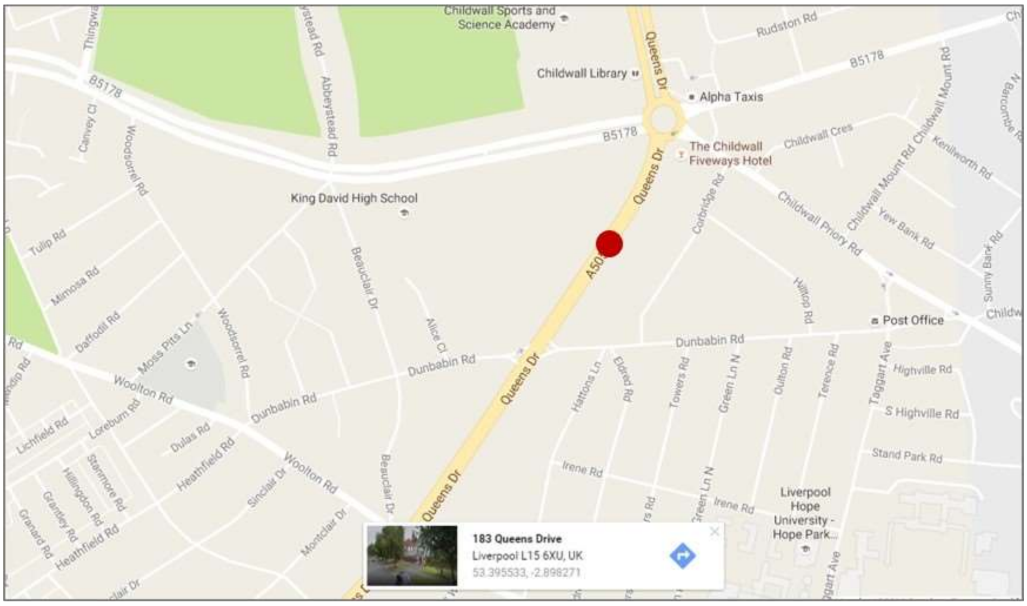
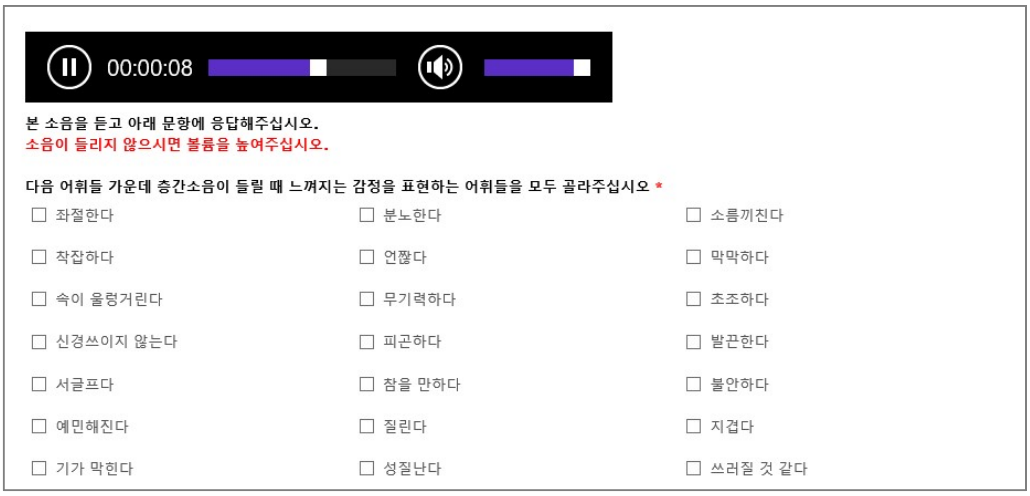


Figure A3-1. The location where the outdoor road traffic noise recording was conducted.

Figure A3-2. Outside of the audiometric booth: wireless amplifiers for physiological data recordings, computers for stimuli presentation and data acquisition.

Appendix 4 Pictures of the online surveys in Chapter 6



본 소음을 듣고 아래 문항에 응답해주십시오.
소음이 들리지 않으시면 볼륨을 높여주십시오.

다음 어휘들 가운데 층간소음이 들릴 때 느껴지는 감정을 표현하는 어휘들을 모두 골라주십시오 *

- ☐ 좌절한다
- ☐ 착잡하다
- ☐ 속이 울렁거린다
- ☐ 신경쓰이지 않는다
- ☐ 서글프다
- ☐ 예민해진다
- ☐ 기가 막힌다
- ☐ 분노한다
- ☐ 언짢다
- ☐ 무기력하다
- ☐ 피곤하다
- ☐ 참을 만하다
- ☐ 질린다
- ☐ 성질난다
- ☐ 소름끼친다
- ☐ 막막하다
- ☐ 초조하다
- ☐ 발끈한다
- ☐ 불안하다
- ☐ 지겹다
- ☐ 쓰러질 것 같다

Figure A4-1. Screen captures of the Survey I which was designed to sample the emotion lexicons.

본 소음을 듣고 아래 문항에 응답해주십시오.
소음이 들리지 않으시면 볼륨을 높여주십시오.

만일 지금 재생되는 소음이 귀하의 집에서 들린다고 가정할 때, 아래 감정을 나타내는 어휘들은 귀하의 감정과 얼마나 어울리나요?

	전혀 1	2	3	4	엄청나게 5
짜증난다 *	○	○	○	○	○
예민해진다 *	○	○	○	○	○
신경질난다 *	○	○	○	○	○
불편하다 *	○	○	○	○	○
신경쓰인다 *	○	○	○	○	○
불쾌하다 *	○	○	○	○	○
언짢다 *	○	○	○	○	○
기분 나쁘다 *	○	○	○	○	○
달갑지 않다 *	○	○	○	○	○
불만스럽다 *	○	○	○	○	○

Figure A4-2. Screen captures of the Survey II which was designed to cluster the emotion lexicons.

Appendix 5 Pictures of the field study in Chapter 7

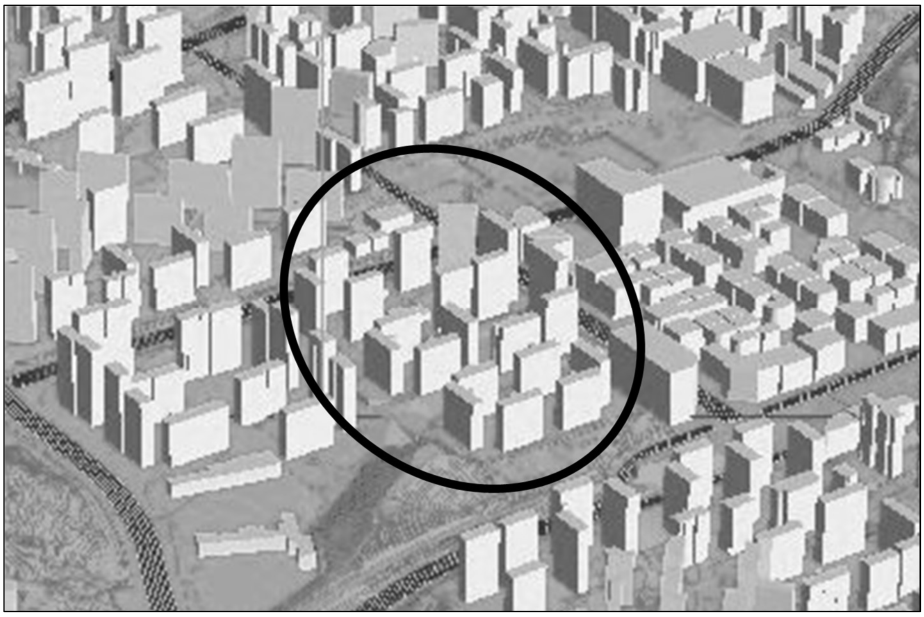


Figure A5-1. The layout of the buildings at Site A.

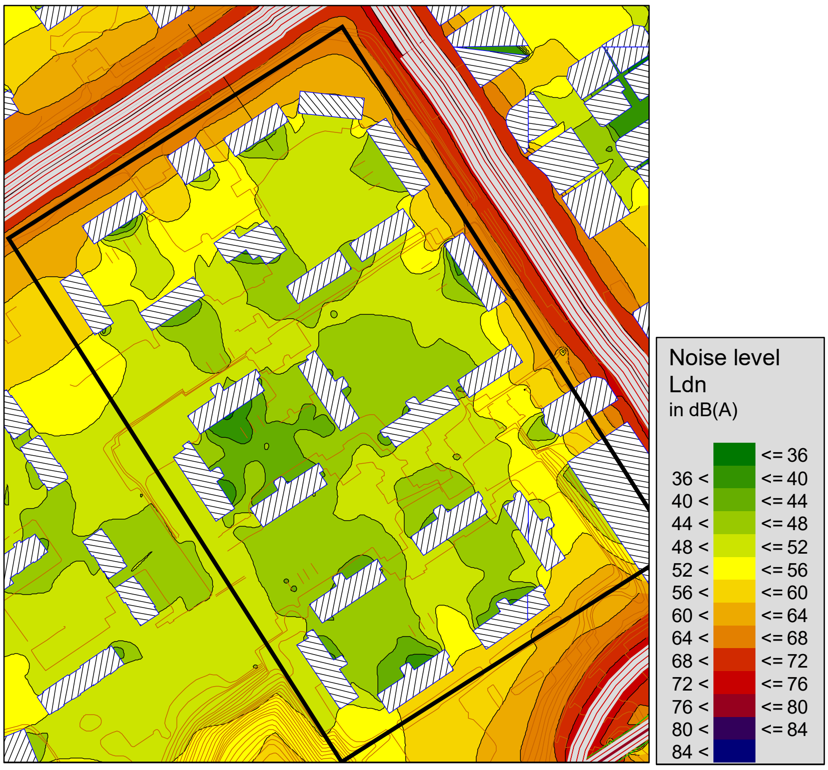


Figure A5-2. Grid noise map of Site A. The L_{dn} were predicted 1.2 m above the ground.

Figure A5-3. The layout of the buildings at Site B.

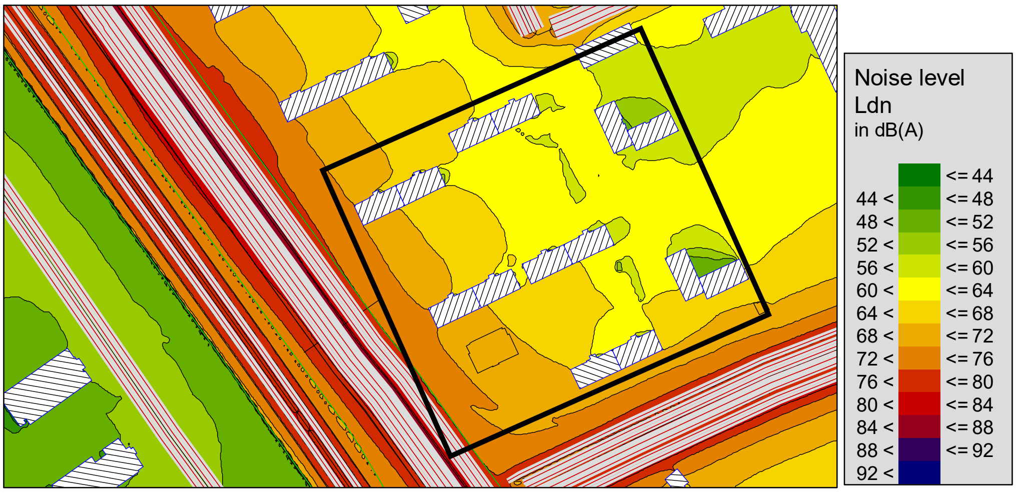


Figure A5-4. Grid noise map of Site B. The L_{dn} were predicted 1.2 m above the ground.

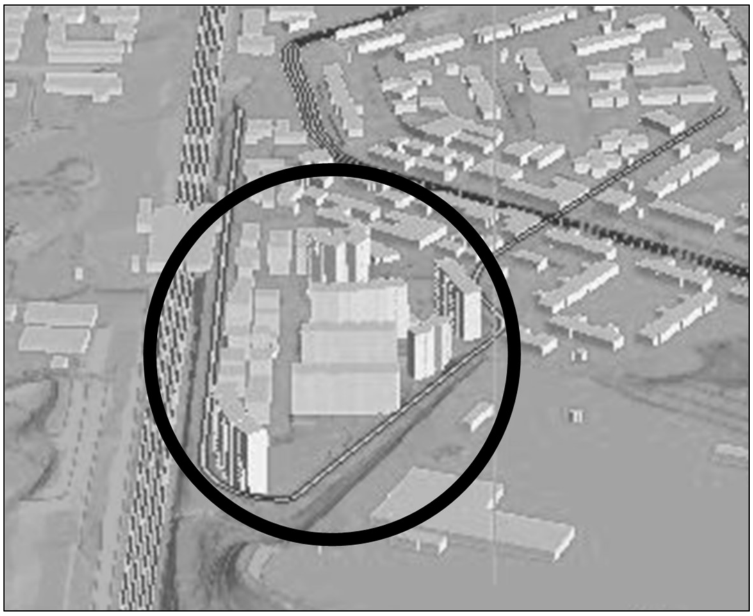


Figure A5-5. The layout of the buildings at Site C.

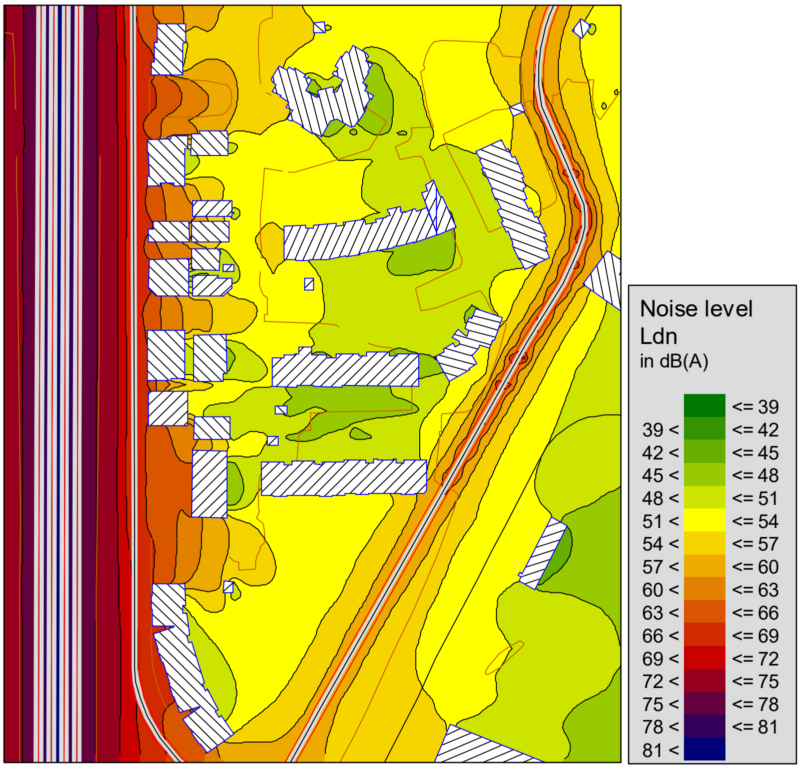


Figure A5-6. Grid noise map of Site C. The L_{dn} were predicted 1.2 m above the ground.

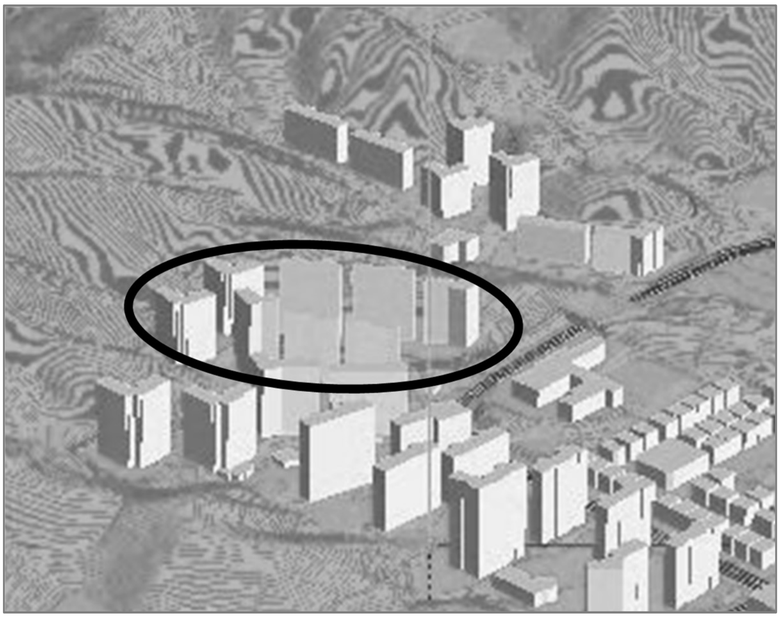


Figure A5-7. The layout of the buildings at Site D.

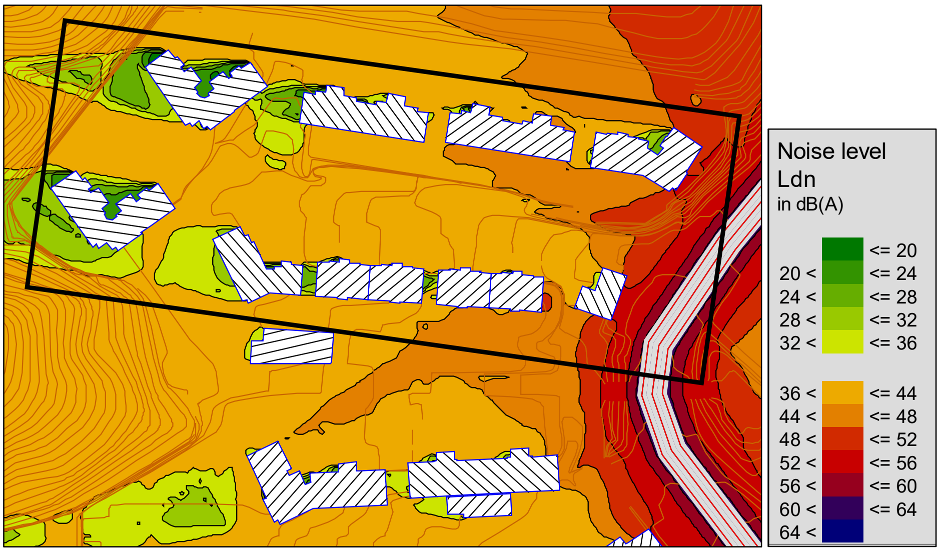


Figure A5-8. Grid noise map of Site D. The L_{dn} were predicted 1.2 m above the ground.

Figure A5-9. Posters (top) and banners (bottom) used at the sites for recruiting participants.

Figure A5-10. Sound level metres were installed on top of buildings at each site for the 24-outdoor noise measurements (left) and the participants visited the separated room within the management office of each site to respond to the questionnaire and to measure blood pressure (right).

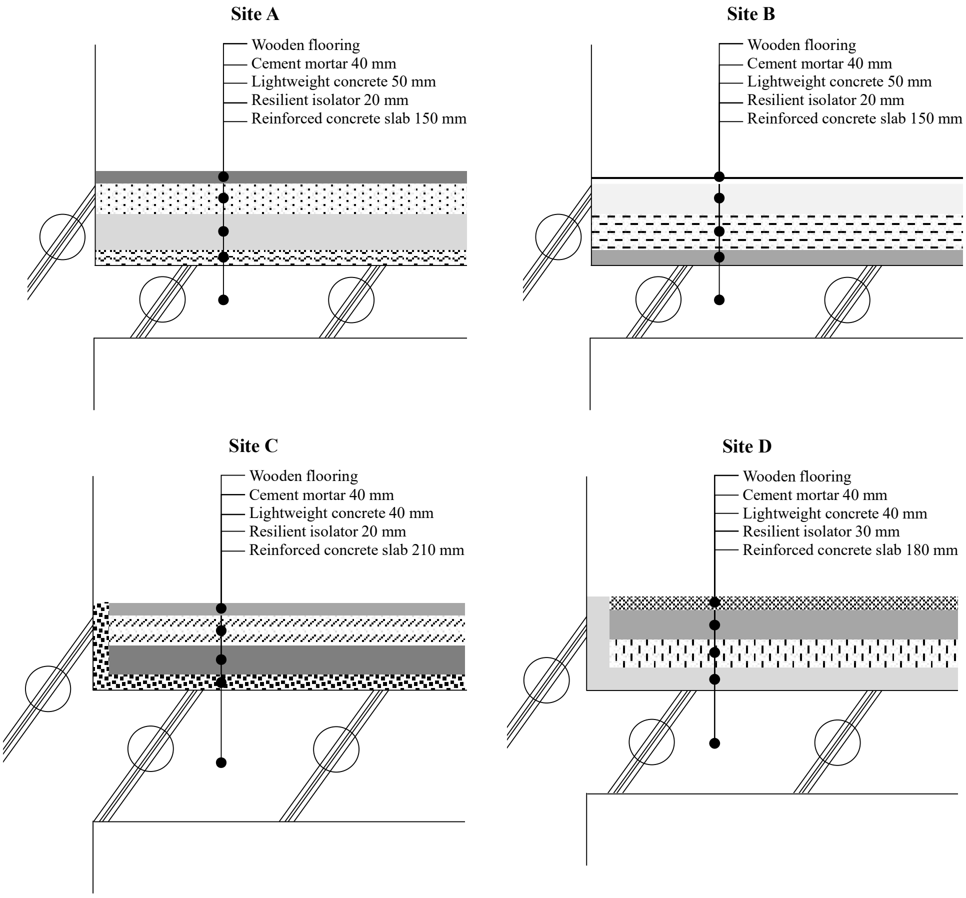


Figure A5-11. Floor structure of each site. The floors of all sites contained reinforced concrete slab, resilient isolator, lightweight concrete, and cement mortar with different thicknesses and they were finished by wooden floorings.

Appendix 6 Information about each interviewee and sample interview excerpts in which conditions were implied (Chapter 8)

<table>
<tr><th>No.</th><th>Age</th><th>Gender</th><th>Child^a</th><th>Length^b</th><th>House ownership</th><th>Complaints^c</th></tr>
<tr><td>1</td><td>24</td><td>M</td><td>No</td><td>2 ~ 5</td><td>Renter</td><td></td></tr>
<tr><td></td><td colspan="6">“I am very sensitive to noise (noise sensitivity) ... I can’t concentrate if somebody starts talking or whispering to someone at the library ... but I’m fine with the people upstairs. I can hear their footsteps but it doesn’t bother me ... I think I’m okay with low-frequency noises (noise source).”</td></tr>
<tr><td>2</td><td>28</td><td>M</td><td>Yes</td><td>1 ~ 2</td><td>Renter</td><td>Contacted the management office</td></tr>
<tr><td>3</td><td>29</td><td>F</td><td>No</td><td>2 ~ 5</td><td>Owner</td><td>Contacted the management office;
Talked to the neighbours on the phone</td></tr>
<tr><td>4</td><td>30</td><td>F</td><td>No</td><td>1 ~ 2</td><td>Owner</td><td></td></tr>
<tr><td>5</td><td>30</td><td>M</td><td>Yes</td><td>2 ~ 5</td><td>Owner</td><td>Contacted the management office</td></tr>
<tr><td>6</td><td>31</td><td>F</td><td>Yes</td><td>2 ~ 5</td><td>Renter</td><td></td></tr>
<tr><td>7</td><td>32</td><td>F</td><td>No</td><td>1 ~ 2</td><td>Owner</td><td></td></tr>
<tr><td></td><td colspan="6">“I went upstairs on the day I was moving in. I brought some cake (priority of building a positive relationship). They asked me to come in (positive attitude shown by the neighbours) and we spent about an hour talking, having tea and the cake I brought ... I’m lucky to have such good friends as my neighbours ... I can understand [the noise exposure]. Everyone makes noise in their everyday life.”</td></tr>
<tr><td>8</td><td>32</td><td>F</td><td>No</td><td>15 <</td><td>Owner
*living with parents</td><td></td></tr>
<tr><td>9</td><td>32</td><td>F</td><td>Yes</td><td>2 ~ 5</td><td>Renter</td><td>Talked to the neighbours on the phone</td></tr>
<tr><td>10</td><td>32</td><td>M</td><td>No</td><td>< 1</td><td>Owner</td><td></td></tr>
<tr><td>11</td><td>33</td><td>M</td><td>Yes</td><td>1 ~ 2</td><td>Renter</td><td>Contacted the management office</td></tr>
<tr><td>12</td><td>33</td><td>M</td><td>Yes</td><td>5 ~ 10</td><td>Owner
*living with parents</td><td>Contacted the management office;
Talked to the neighbours face-to-face in the lift</td></tr>
<tr><td>13</td><td>34</td><td>F</td><td>No</td><td>2 ~ 5</td><td>Renter</td><td></td></tr>
<tr><td>14</td><td>34</td><td>M</td><td>No</td><td>15 <</td><td>Owner
*living with parents</td><td></td></tr>
<tr><td></td><td colspan="6">“I’ve met them, a few times in the lift or just in front of the building ... Both of them are teachers (lack of uncertainty: knowledge about the neighbours) ... I don’t think they are noisy ... I can hear their footsteps in the morning ... not very early [in the morning] (time of noise exposure; predictability) ... I usually wake up at seven [7 am] and I can hear them from half seven or eight ... just for one or two hours (length of noise events). I think they are busy getting ready to go to work in the morning.”</td></tr>
<tr><td>15</td><td>34</td><td>M</td><td>Yes</td><td>2 ~ 5</td><td>Owner</td><td></td></tr>
<tr><td></td><td colspan="6">“I had bad experiences [with previous neighbours] when I lived in my previous house (history with previous neighbours) ... I called the police one night ... I was really, really angry ... I had already called the management office so many times ... The relationship [between the neighbours and me] got worse since then ... So I didn’t want to talk to them [the current neighbours] when they moved in. Who knows? They could be the same [with previous neighbours]. But they [the current neighbours] seem okay, [they are] quite friendly. (friendly attitude shown by the neighbours)”</td></tr>
</table>

No.	Age	Gender	Child[a]	Length[b]	House ownership	Complaints[c]
16	34	M	Yes	< 1	Owner	Contacted the management office
17	35	F	Yes	5 ~ 10	Renter	
18	35	F	Yes	2 ~ 5	Owner	
19	35	F	Yes	1 ~ 2	Renter	
20	35	M	Yes	5 ~ 10	Renter	Contacted the management office; Talked to the neighbours on the phone
21	36	F	Yes	2 ~ 5	Owner	
	“I can hear some noise like the dragging around of the vacuum machine, or the noise of the washing machine spinning, especially when it drains ... I’m okay with that as I can’t hear it when it’s late at night, I can hear it only during the daytime (time of noise exposure).”					
22	36	M	Yes	5 ~ 10	Owner	Talked to the neighbours on the phone; Talked to the neighbours face-to-face in the lift and corridor
	It’s very quiet at night, so I can hear their noise more clearly (ambient noise) ... I can understand if it’s noisy before ten [10 pm] but after that, they should be careful [not to make noise], even walking, I don’t understand why they need to walk around the house that much at night (time of noise exposure).					
23	36	M	Yes	< 1	Owner	Talked to the neighbours on the phone
	“We moved in last year (short length of residency) ... It’s in a perfect location for all of us [himself, his wife, and their children], our offices and schools are closed (positive attitude towards the house) ... It’s such a big complex, there are still people we meet for the first time and my wife and I still introduce ourselves to neighbours (priority of building positive relationships with neighbours) ... I’ve called them once, with the interphone, I spoke [about the noise] very politely. She [upstairs neighbour who received the call] complained their feet hurt as they’ve been only walking on their tiptoes. She was quite angry with me that time (negative attitude shown by the neighbours) ... now I just keep saying hello and smiling when I see them, they don’t smile but say hello ... Maybe we were too stressed at that time [when we made the complaints] by different sorts of things, such as from work.”					
24	37	F	Yes	2 ~ 5	Owner	Talked to the neighbours on the phone
	“They are very social, we became friends not so long after they moved in (friendly/social attitude shown by the neighbours) ... I just call them and say ‘hey, can you please be quiet?’”					
25	38	F	No	< 1	Owner	Contacted the management office
26	38	F	No	1 ~ 2	Renter	
27	38	M	Yes	5 ~ 10	Owner	Contacted the management office
28	39	F	No	2 ~ 5	Owner	Left a letter to the neighbours
29	39	M	Yes	10 ~ 15	Owner	Contacted the management office; Contacted the government authority; Made revengeful noises

<table>
<tr><th>No.</th><th>Age</th><th>Gender</th><th>Child[a]</th><th>Length[b]</th><th>House ownership</th><th>Complaints[c]</th></tr>
<tr><td>30</td><td>40</td><td>F</td><td>No</td><td>1 ~ 2</td><td>Owner</td><td>Contacted the management office;
Left a letter to the neighbours</td></tr>
<tr><td>31</td><td>40</td><td>M</td><td>No</td><td>2 ~ 5</td><td>Owner</td><td>Contacted the management office</td></tr>
<tr><td>32</td><td>40</td><td>M</td><td>Yes</td><td>< 1</td><td>Renter</td><td>Contacted the management office;
Talked to the neighbours on the phone</td></tr>
<tr><td></td><td colspan="6">“He [upstairs neighbours’ child] is around four [years old] and he never stops running and jumping (children upstairs: noise source). I sometimes don’t understand them ... Do they [upstairs neighbours] even try [to stop him making the noise]? I can understand if it’s just a couple of times a day but ... he keeps running and jumping until he goes to bed at night ... every day (frequency and length of noise exposure).”</td></tr>
<tr><td>33</td><td>41</td><td>F</td><td>No</td><td>1 ~ 2</td><td>Owner</td><td>Contacted the management office</td></tr>
<tr><td>34</td><td>41</td><td>F</td><td>Yes</td><td>2 ~ 5</td><td>Owner</td><td></td></tr>
<tr><td></td><td colspan="6">“I’m fine with them ... I don't know much about them (lack of information about the neighbours) ... I think they moved in not so long ago (short history) ... I can occasionally hear them, their footsteps ... but they are not loud at all (noise level).”</td></tr>
<tr><td>35</td><td>41</td><td>M</td><td>No</td><td>2 ~ 5</td><td>Owner</td><td>Contacted the management office;
Talked to the neighbours on the phone;
Contacted the government authority;
Made revengeful noises</td></tr>
<tr><td></td><td colspan="6">“They made me crazy. They never stop (history, frequency or length of noise exposure) ... I think I can understand why those people on TV killed their neighbours. I’m not saying I want to do something to harm them [upstairs neighbours] but I’m just saying that I know how they [people on the news who committed the crime to their neighbours] might have felt ... There are many holes in my ceiling as I’ve hit my ceiling with a golf club. I know it’s destroying my house ... I can’t put up with them. I’m 100 percent sure they make noise intentionally ... jumping with shoes, heels (attitudes shown by neighbours: revengeful noise exposure)! Have you seen anybody wearing shoes in their house ... It’s a headache ... I think of what I should do with them every day ... I’ve installed three loudspeakers on my ceiling. They work quite well ... I turn them [the speakers] on if they [neighbours] are noisy at night (time of noise exposure).”</td></tr>
<tr><td>36</td><td>41</td><td>M</td><td>Yes</td><td>< 1</td><td>Renter</td><td></td></tr>
<tr><td>37</td><td>42</td><td>M</td><td>Yes</td><td>< 1</td><td>Owner</td><td></td></tr>
<tr><td>38</td><td>42</td><td>M</td><td>Yes</td><td>5 ~ 10</td><td>Owner</td><td></td></tr>
<tr><td></td><td colspan="6">“They have two children (children at neighbours’: noise source). You know, kids should run, that’s how they grow, that’s how we know they are healthy (children at home: experience of living with children) ... We [my wife and I] were going out for a walk and saw them for the first time outside the building when they were moving in. We just asked them ‘Hi, are you moving into this building?’ and they said they were moving into the 11th floor. We introduced ourselves and told them we are on the 10th floor ... you know, you can’t cook when you have just moved into a new house, you just get food delivered until the kitchen is sorted. So we invited them to ours that evening for dinner, and for the next couple of days as well (priority of building and maintaining positive relationships with neighbours).”</td></tr>
<tr><td>39</td><td>43</td><td>F</td><td>No</td><td>2 ~ 5</td><td>Owner</td><td></td></tr>
</table>

<table>
<tr><th>No.</th><th>Age</th><th>Gender</th><th>Child[a]</th><th>Length[b]</th><th>House ownership</th><th>Complaints[c]</th></tr>
<tr><td>40</td><td>44</td><td>F</td><td>Yes</td><td>2 ~ 5</td><td>Renter</td><td>Contacted the management office;
Talked to the neighbours on the phone</td></tr>
<tr><td></td><td colspan="6">“I’ve asked the [management] office quite a few times to ask them [neighbours] to be quiet (history of making complaints). She [management officer] said they would [stop making noise] (expectation that the noise would stop) ... I ended up calling them [neighbours] last night as they didn’t stop [making noise] ... I think I’ll be very upset if I have to ask them to be quiet again. I’ll have to wait and see.”</td></tr>
<tr><td>41</td><td>44</td><td>F</td><td>No</td><td>1 ~ 2</td><td>Owner</td><td>Contacted the management office</td></tr>
<tr><td>42</td><td>44</td><td>F</td><td>Yes</td><td>2 ~ 5</td><td>Owner</td><td></td></tr>
<tr><td></td><td colspan="6">“There are three children living upstairs (children upstairs: noise source). Very, very noisy children ... They are friendly to my daughter whenever we meet them at the playground ... The mum [the children’s mother] is also very friendly (children at home; friendly attitude shown by the neighbours) ... we are all friends ... She told me my daughter can come upstairs and play with her kids. Since then, I just send her [the daughter] upstairs when it gets noisy.”</td></tr>
<tr><td>43</td><td>44</td><td>F</td><td>Yes</td><td>5 ~ 10</td><td>Owner</td><td></td></tr>
<tr><td>44</td><td>44</td><td>M</td><td>Yes</td><td>2 ~ 5</td><td>Owner</td><td></td></tr>
<tr><td></td><td colspan="6">“They are quite nice people. I am totally fine with them ... they always come down and tell us in advance (predictability; considerate attitudes shown by the neighbours) if something’s happening, like a family gathering or a party with friends ... [neighbours have people around] once every month or two (frequency of noise events).”</td></tr>
<tr><td>45</td><td>45</td><td>F</td><td>No</td><td>1 ~ 2</td><td>Renter</td><td></td></tr>
<tr><td>46</td><td>45</td><td>F</td><td>No</td><td>5 ~ 10</td><td>Owner</td><td>Visited the neighbours;
Contacted the police</td></tr>
<tr><td></td><td colspan="6">“I’ll always remember the date and time, it was October 21st two years ago, it was 1:15 am. I went upstairs, knocked on the door and rang the bell several times until she opened the door. I told her they had been very noisy for many hours and that it was too late (time of noise exposure). However, she stopped me talking and shouted at me, saying that I didn’t know how to get along with neighbours in this type of housing (negative attitude shown by the neighbour). I came back [home] and called the police ... They have been noisy so many times and I have put up with them for so long (history). The management office had contacted them several times before but they never changed ... We don’t see each other even in the same lift. I don’t want to see them. I really hope they’ll move out ... I haven’t seen anyone like them before.”</td></tr>
<tr><td>47</td><td>45</td><td>F</td><td>Yes</td><td>2 ~ 5</td><td>Renter</td><td></td></tr>
<tr><td>48</td><td>45</td><td>M</td><td>No</td><td>1 ~ 2</td><td>Owner</td><td>Contacted the management office</td></tr>
<tr><td>49</td><td>46</td><td>F</td><td>No</td><td>5 ~ 10</td><td>Owner</td><td></td></tr>
<tr><td></td><td colspan="6">“Who can spit at a smiley face? ... They brought some fruit when they first moved in and apologised (apologetic attitude shown by the neighbours) as they have children (children at neighbours’: noise source) ... they have brought cakes, juice, fruit since then ... I’ve told them that they do not need to do so [bring something] several times but they keep bringing something and keep apologising every time I see them in the lift ... I know they are good people, but I think I’m quite sensitive (noise sensitivity) ... Sometimes, when I’m tired, I’m annoyed by the noise of kids running, but I just can’t tell them. I feel sorry.”</td></tr>
</table>

<table>
<tr><th>No.</th><th>Age</th><th>Gender</th><th>Child[a]</th><th>Length[b]</th><th>House ownership</th><th>Complaints[c]</th></tr>
<tr><td>50</td><td>46</td><td>F</td><td>No</td><td>10 ~ 15</td><td>Owner</td><td>Contacted the management office;
Left a letter to the neighbours</td></tr>
<tr><td></td><td colspan="6">“I can’t hear it, but my husband says he can! He says he can’t fall asleep and he gets really annoyed sometimes ... He is very sensitive to noise (noise sensitivity), he says he gets more distracted by noise than others at work ... He says they [neighbours] are very rude being noisy at night (time of noise exposure).”</td></tr>
<tr><td>51</td><td>46</td><td>M</td><td>Yes</td><td>5 ~ 10</td><td>Owner</td><td>Contacted the management office;
Talked to the neighbours on the phone;
Talked to the neighbours face-to-face in the lift;
Contacted the government authority</td></tr>
<tr><td></td><td colspan="6">“I’ve done everything ... Anything I can do to solve this problem (history; goal to solve the noise problem) ... I’ve called the centre [Floor Noise Management Centre] and they said they could come and measure the noise levels and see if the levels exceed that in the regulation ... that means they [upstairs neighbours] should make noise when the people from the centre come. How can I predict they [upstairs neighbours] will make noise (uncertainty or lack of predictability)? I have no idea when they are going to make noise, that’s why I get crazy ... It seems the centre is for those who have problems between neighbours to mediate the disputes.”</td></tr>
<tr><td>52</td><td>47</td><td>M</td><td>No</td><td>10 ~ 15</td><td>Owner</td><td>Contacted the management office</td></tr>
<tr><td>53</td><td>48</td><td>M</td><td>No</td><td>10 ~ 15</td><td>Owner</td><td>Contacted the management office;
Talked to the neighbours on the phone</td></tr>
<tr><td>54</td><td>48</td><td>M</td><td>No</td><td>15 <</td><td>Owner</td><td>Talked to the neighbours face-to-face outside the building</td></tr>
<tr><td>55</td><td>51</td><td>F</td><td>No</td><td>15 <</td><td>Renter</td><td>Contacted the management office;
Talked to the neighbours on the phone</td></tr>
<tr><td>56</td><td>61</td><td>F</td><td>No</td><td>10 ~ 15</td><td>Owner</td><td></td></tr>
<tr><td></td><td colspan="6">“I don’t mind it. They [children upstairs] are just kids and it’s very difficult to control them (children upstairs: noise source), I know that. My children did the same (experience of living with children in the past), kids just run all the time.”</td></tr>
<tr><td>57</td><td>65</td><td>F</td><td>No</td><td>15 <</td><td>Owner</td><td>Contacted the management office</td></tr>
</table>

[a] Those who lived with any child under 12 years old were asked to select “Yes”.

[b] Length of residency in the current house (in years).

[c] Type of complaints that the interviewee had made regarding the neighbour noise.

Appendix 7 Published papers in peer-reviewed journals and conference proceedings

Journal articles

- Park, S. H., Lee, P. J., & Lee, B. K. (2017). Levels and sources of neighbour noise in heavyweight residential buildings in Korea. Applied Acoustics, 120, 148-157.
- Park, S. H., & Lee, P. J. (2017). Effects of floor impact noise on psychophysiological responses. Building and Environment, 116, 173-181.
- Park, S. H., Lee, P. J., & Jeong, J. H. (2018). Effects of noise sensitivity on psychophysiological responses to building noise. Building and Environment, 136, 302-311.
- Park, S. H., Lee, P. J., & Jeong, J. H. (2018). Emotions evoked by exposure to footstep noise in residential buildings. Plos One, 13(8), e0202058.
- Park, S. H., Lee, P. J., & Jeong, J. H. (2019). Reaction to floor impact noise in multi-storey residential buildings: The effects of acoustic and non-acoustic factors. Applied Acoustics, 150, 268-278.

Conference papers

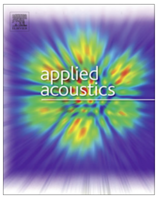
- Lee, P. J., & Park, S. H. (2016). An experimental study of psychophysiological responses to floor impact sounds. Paper presented at the INTER-NOISE and NOISE-CON Congress and Conference Proceedings, Hamburg, Germany.
- Park, S. H., & Lee, P. J. (2017). Effects of floor impact noise on people – annoyance and physiological responses. Paper presented at the International congress on noise as a public health problem, ICBEN, Zurich, Switzerland.
- Park, S. H., Lee, P. J., & Jeong, J. H. (2017). Influence of noise sensitivity on physiological responses to floor impact sounds. Paper presented at the International Congress on Sound and Vibration, ICSV, London, UK.
- Park, S. H., & Lee, P. J. (2018). Effects of indoor and outdoor noise on residents' annoyance and blood pressure. Paper presented at the European congress and exposition on noise control engineering, Euronoise, Crete, Greece.

Applied Acoustics 120 (2017) 148–157

Contents lists available at ScienceDirect

Applied Acoustics

journal homepage: www.elsevier.com/locate/apacoust



Levels and sources of neighbour noise in heavyweight residential buildings in Korea

Sang Hee Park [a], Pyoung Jik Lee [a,*], Byung Kwon Lee [b]

[a] Acoustics Research Unit, School of Architecture, University of Liverpool, Liverpool, UK
[b] Korea Environment Institute, 370 Sicheong-daero, Sejong, 30147, Republic of Korea

ARTICLE INFO

Article history:
Received 11 August 2016
Received in revised form 6 January 2017
Accepted 11 January 2017

Keywords:
Indoor environment
Neighbour noise
Noise level
Noise source
Residential building

ABSTRACT

Indoor noise level is a significant factor for occupants' health, comfort, and psychological well-being in residential buildings; hence the World Health Organization (WHO) recommends guidelines for residential buildings based on the 24-h sound levels. However, only few studies have examined 24-h noise levels and sources from neighbours. Consequently, 24-h noise measurement is necessary for understanding noise level and acoustic comfort in homes. Field measurements were performed in 26 residential apartments in Korea to investigate levels and types of noise from neighbours. Noise recordings were carried out at each residence in unoccupied conditions. The recordings were analysed at 1 min intervals in terms of the A-weighted equivalent (L_{Aeq}) and maximum sound pressure levels (L_{AFmax}) for three different time periods during the day. It was found that 20 apartments met the recommended WHO guidelines during the daytime (07:00–23:00). However, at night (23:00–07:00), eight apartments were in excess of the WHO guideline value in terms of L_{Aeq} while L_{AFmax} exceeded the WHO limit level in 22 apartments during the night. Human footsteps, movement of furniture, and dropping of small items were found to be major sources accounting for approximately 80% of all the noise events. L_{AFmax} of children's jumping and dropping small items were greater than others. Adults' walking showed larger variation of noise levels than other sources. Moreover, it was found that indoor noise levels were not affected by slab thickness and major noise sources.

1. Introduction

Noise has been considered as a threat to public health and well-being [1]. Several studies have reported that chronic exposure to noise can cause annoyance, sleep disturbance, and health problems. Miedema [2] argued the significant effect of transportation noise on the prevalence of noise annoyance. It has been known that noise has not only auditory health effects (e.g., hearing loss, noise-induced hair-cell damage) but also various non-auditory health risks such as daytime sleepiness or it can impair cognitive performance in schoolchildren [3,4]. It was also reported that aircraft and road traffic noise has a high impact on cardiovascular health (e.g., high blood pressure, ischemic heart diseases) [5].

However, the majority of work has mainly focused on environmental noise such as road traffic noise and railway noise. In contrast, few studies have investigated the impact of neighbour noise on residents' psychophysiological well-being. Maschke et al. [6] conducted a cross-national questionnaire surveys in eight European cities and found that annoyance caused by neighbour noise increased health risks in the cardio-vascular system. But noise exposure level at home is unknown because they did not perform noise measurement. Pujol et al. [7] investigated children's exposure to noise at home in an urban area by measuring long-term indoor noise levels at homes. They were mainly concerned with noise from outside rather than indoor noise sources, and noise sources were not identified during the measurements [7]. Therefore, it is still unknown which indoor noise sources contribute to noise levels in residential buildings.

In order to examine the health effects of environmental noise exposure, 24-h noise measurements have commonly been conducted [8,9]. Several noise descriptors such as day-night level (DNL) and day-evening-night level (DENL) have been introduced to describe overall noise exposure for 24 h. Noise measurements for 24 h or working hours have also been occasionally performed in non-residential buildings such as hospitals and offices [10,11]. On the other hand, very little data exists describing 24-h noise exposure and most previous studies on residential buildings measured only short-term indoor noise levels. Jeon et al. [12] measured

---

* Corresponding author at: Acoustics Research Unit, School of Architecture, University of Liverpool, Liverpool L69 7ZN, UK.

E-mail address: p.j.lee@liverpool.ac.uk (P.J. Lee).

http://dx.doi.org/10.1016/j.apacoust.2017.01.012
0003-682X/© 2017 The Authors. Published by Elsevier Ltd.

noise levels while the apartment was empty and the windows were closed. Lai et al. [13] measured the noise levels for 15 min in 32 residential apartments and the average noise levels for 15 min were found to be 67.1 dBA with a variation from 52 to 77.9 dBA. Noise levels for one hour were also measured in urban residential buildings under a natural ventilation condition [14]. Similarly, Pujol et al. [7] measured the noise levels in bedrooms and the main rooms to analyse children's exposure to environmental noise at home. They found the averages of noise levels for day, evening, and night in 44 dwellings were 51.3, 53.6, and 36.9 dBA, respectively. However, short-term field measurements only represent a snapshot condition of an indoor built environment at a specific time. In addition, the World Health Organization (WHO) recommends guidelines for residential buildings in terms of the average sound levels for 16 h (daytime) and eight hours (night) [1]. Therefore, 24-h noise measurement in residential buildings is required to improve our understanding of noise level and acoustic comfort at homes.

The majority of dwelling types in South Korea are multi-story and heavyweight (i.e. reinforced concrete) apartment buildings [15]. In multi-story buildings, residents are easily exposed to a number of noises from their neighbours, thus a large number of complaints regarding dwelling noise have been raised by apartment residents [15]. In order to resolve noise problems in apartment buildings, multi-layered floor structures, consisting of a concrete slab, resilient isolator, lightweight concrete, and finishing mortar, have been used. In addition, the Korean Government strengthened the domestic regulations in 2005 and 2007 by increasing the concrete slab thickness to 180 mm and 210 mm, respectively [16] because the slab thickness of the apartments mostly ranged between 135 mm and 150 mm before 2005. Empirical studies [17,18] supported the decision of the Korean Government reporting that the impact sound insulation of the floors had improved with the increases of the concrete slab thickness. According to Jeong et al. [18], a 30 mm increase of slab thickness led to an increase of heavyweight impact sound insulation of 2 dB. However, contrary to expectations, the complaints of neighbours' noises have still increased; number of complaints about floor impact sound recorded in the Ministry of Environment of Korean Government increased from 114 in 2005 to 341 in 2010. However, the complaints were also raised from residents living in old apartments built before 2005, so it is still unknown whether or not increased slab thickness is effective in reducing indoor noise levels in real buildings.

The present study aims to determine noise levels and noise sources from neighbours in residential buildings. It is hypothesised that noise levels are influenced by noise sources and that indoor noise levels are hypothesised to be affected by slab thickness. To validate these hypotheses, 24-h noise measurements were conducted in the living rooms of 26 residential apartments. During the measurements, the apartments were empty and windows were closed to minimise the influence of outdoor noise on indoor noise levels. The recording were analysed in terms of the equivalent and maximum noise levels (L_{Aeq} and L_{AFmax}, respectively) based on three time periods of the day: day (07:00–19:00), evening (19:00–23:00), and night (23:00–07:00). Furthermore, noise sources from neighbours were identified by listening to the recordings and the levels of each noise source were analysed.

2. Method

2.1. Sites

Twenty-six reinforced concrete apartments were selected for the 24-h noise recordings. Of these, 15 were in Seoul and others were located in cities nearby Seoul. As listed in Table 1, the net floor areas of the apartments ranged from 42.0 to 212.5 m^2. The number of bedrooms in each home varied from two to five. The house age also varied; the oldest apartment was built 32 years ago and the latest one was just 3 years old. Slab thicknesses of the apartment buildings varied from 135 mm to 210 mm; the apartments built before the domestic regulation was strengthened in 2005 had slab thickness of 135 mm and 150 mm. Sizes of groups were quite similar; 14 sites were classified into Group 1, while Group 2 had 12 sites. This distinction was made because the Korean Government introduced a domestic regulation requiring construction companies to increase the concrete floor slab thickness by 30 mm at that time. Most homes under measurement were away from traffic roads, which provides a relatively consistent environmental noise condition.

2.2. Procedure

Noise levels in living rooms were measured under unoccupied conditions from the morning to the following morning for 24-h periods while the residents were vacated. The windows in the living rooms and balconies of all the homes were closed during the measurements to minimise the effects of outdoor noise. All the windows were double glazed and the balconies were adjacent to the living rooms at all sites; thus, it was expected that the influence of outdoor noise on indoor noise levels is limited. The measurements were performed only during weekdays to avoid influences of neighbour's daily activities on the recordings. The noise was recorded using a half-inch free field microphone (B&K Type 4189) positioned at a sitting position in the living rooms. The microphone was directly connected to the noise monitoring system (DUO, 01 dB) which has the calibrated recording feature as all-in-one device. The noise levels were monitored continuously for 24 h and noise was recorded whenever the noise level exceeded 30 dBA (L_{Aeq}) at a sample rate of 51.2 kHz. The recordings were then transferred to a laptop computer. Before the data collection, the entire measurement system was calibrated using an acoustic calibrator (B&K Type 4280).

2.3. Data analysis

One-minute interval noise level data were exported from the noise monitoring system (DUO, 01 dB). The data were then processed using dBTrait software from 01dBmetravib. According to the WHO guidelines [1], all noise events for 1 min, and 2) A-weighted maximum sound pressure level (L_{AFmax}) of the noise event. The L_{AFmax} was calculated using the 'fast' time constant for analyses of the recorded noises. The WHO guideline recommends the noise levels for daytime (07:00–23:00) and night time (23:00–07:00); however, in the present study, 24-h period is classified into the day (07:00–19:00), evening (19:00–23:00), and night (23:00–07:00) according to ISO 1996-2 [19].

In order to identify the noise source, the occurrence of the noise events was defined as an event exceeding the WHO recommended values for day and night noise in dwellings. During the daytime, the recommended values are 35 dBA (L_{Aeq}), while the values for the night are 30 dBA (L_{Aeq}) and 45 dBA (L_{AFmax}). The present study also set the threshold L_{AFmax} value for the daytime as 50 dBA, which is adopted from the domestic guidelines of the Korean Government. Firstly, the noise levels exceeding the recommended value were identified based on the one-minute interval noise level data. Secondly, the noise sources and lengths of the noise events were then manually recognised by listening to small sections of the recordings and visually observing time histories as an interval of 125 ms. All airborne and structure-borne noise events were identified; of structure-borne noise sources, heavyweight and

Table 1
Information of apartments at which indoor noise levels were measured.

No.	House age [year]	Floor area [m^2]	Number of bedrooms	Number of floors[a]	Slab thickness [mm]	Distance from road [m]	Number of lanes per side
1	23	42.0	2	9/17	150	79	2
2	27	62.6	2	1/5	135	80	3
3	10	107.7	3	4/23	180	51	1
4	5	101.5	3	7/11	210	123	4
5	4	131.5	3	14/17	210	61	3
6	11	99.8	3	7/18	180	51	2
7	13	88.0	3	18/22	150	56	1
8	12	151.0	4	3/13	150	25	4
9	16	108.5	3	13/24	150	92	3
10	12	106.9	3	7/16	150	106	4
11	11	107.6	2	11/42	180	41	4
12	13	96.7	3	4/7	150	46	3
13	11	84.9	3	16/19	180	42	1
14	17	84.5	3	4/15	150	29	2
15	17	109.6	3	13/22	150	37	2
16	3	110.1	3	2/13	210	110	3
17	8	126.6	4	20/21	180	171	5
18	11	114.3	3	12/28	150	87	3
19	32	198.1	5	12/15	135	181	2
20	26	97.0	3	8/15	135	35	1
21	18	107.3	3	10/19	150	31	4
22	7	149.1	4	3/12	180	22	1
23	6	212.5	4	32/34	180	75	3
24	24	193.7	5	2/15	150	26	1
25	10	106.2	3	10/29	150	70	3
26	12	110.0	3	9/15	150	33	1
Mean	13.8	115.7	3.2	–	159.8	67.7	2.5
Standard deviation	7.5	38.8	0.5	–	22	42.6	1.2
Minimum	3	42.0	2	–	135	22	1
Maximum	32	212.5	5	–	210	181	5

[a] The former number is the floor on which the apartment is located; the latter is the total number of the building floors.

lightweight impact sources were also recognised through repetitive manual listening. Several sources were identified based on objective characteristics. For example, adults' walking and children's running were recognised mainly based on step frequency (speed of footstep) and interval between the steps. In addition, other noise sources before and after the footsteps were considered because children's running were usually accompanied by other activities such as playing with toys. Each noise source had a different length; therefore, the noise levels of each source were converted into an A-weighted sound exposure level (L_{AE}), which is the equivalent sound level during the event normalised to a period of one second.

3. Results

3.1. Noise levels

Table 2 lists percentage, median, minimum, and maximum values of $L_{Aeq,1min}$ and L_{AFmax} for the 24 h, day, evening, and night. The data of this study were non-normally distributed ($p = 0.05$, the Shapiro–Wilk test); therefore, the presentation of median values were used throughout the current paper since they are helpful for describing data which is not normally distributed. The median values for L_{Aeq} for 24 h, day, and evening were quite similar and slightly greater than 30 dBA, whereas that of night was less than 30 dBA. It was found that the variation in the noise levels was greatest in the evening followed by night and day. All the outliers above the 5% percentiles were due to loud announcements from the public address (PA) system installed in each home. The median of the L_{AFmax} for 24 h was the greatest, followed by day, evening and night. The boxplot of the L_{AFmax} for 24 h shows the highest median value as it contains all the data of L_{AFmax} for whole day. The medians for 24 h and day were greater than 60 dBA, whereas the median of night was less than 50 dBA. The variation in noise levels at night was much shorter than other periods. For the $L_{Aeq,1min}$, most levels were below 40 dBA, and only less than 1% exceeded 40 dBA. Contrary to the L_{Aeq}, the percentage of the L_{AFmax} exceeding 40 dBA significantly increased. The levels between 30 dBA and 40 dBA showed the highest percentages, and more than 20% of the levels were greater than 40 dBA in the daytime and evening.

3.2. Noise sources

Noise sources and their number of occurrences from 26 apartments are listed in Table 3. Mean and standard deviation are also listed to show how many times each source is heard from each apartment. The noise sources were classified into airborne and structure-borne sound sources according to the sound transmission methods [17]. Five sources were airborne, and these were public address (PA) system, domestic equipment, voice, and other sounds such as musical instruments. It was found that a total of 77 occurrences were produced by airborne sound sources, and the number of occurrences of children's voice was the largest. Similarly, the structure-borne sound source had nine sub-sources such as footsteps and movement of furniture. The number of noise events due to the structure-borne sound sources was 495, which accounts for 86.5% of all noise events. This shows that structure-borne noise sources are dominant in residential apartments. The number of occurrences for movement of furniture was the largest, followed by dropping small items, children's running, and adults' walking. It was observed that only five noise sources had mean values which are greater than 1. This indicates that other noise sources occurred less than once during a 24-h period. However, low number of occurrences does not guarantee acoustic comfort in apartments because only noise events exceeding WHO recommended noise levels was counted in the present study. Table 3 included all the noise sources from above and the neighbouring

Table 2
Percentages, median, minimum, and maximum of one-minute A-weighted equivalent sound levels ($L_{Aeq,1min}$) and A-weighted maximum sound levels (L_{AFmax}).

		Overall 24-h	Day (07:00–19:00)	Evening (19:00–23:00)	Night (23:00–07:00)
$L_{Aeq,1min}$	$\% \leqslant 30$ dBA	57.6	54.1	56.3	63.7
	$30 < \% \leqslant 40$ dBA	42.1	45.6	43.5	36.3
	$40 < \% \leqslant 50$ dBA	0.2	0.3	0.1	0.1
	$\% > 50$ dBA	0	0	0.1	0
	% > threshold		11.1	10.9	36.4
	Median	30.3	30.6	30.1	29.2
	Minimum	20.8	20.2	20.9	19.4
	Maximum	45.7	46.9	48.6	36.2
L_{AFmax}	$\% \leqslant 30$ dBA	20.7	13.6	14.7	34.4
	$30 < \% \leqslant 40$ dBA	63.1	66.2	63.8	58.2
	$40 < \% \leqslant 50$ dBA	14.6	18.2	19.3	6.8
	$\% > 50$ dBA	1.6	2.1	2.2	0.5
	% > threshold		2.1	2.2	2.1
	Median	61	59.7	54.5	49.7
	Minimum	48.8	48.8	45.9	43
	Maximum	87.1	87.1	86.6	70.2

Table 3
Number of occurrence and length of each noise event.

Noise source			Number of occurrence				Length		
			Number	%	Mean	Standard deviation	Median	Minimum	Maximum
Airborne sound source	PA system		11	1.9	0.4	0.9	62.5	43	113.8
	Domestic equipment		2	0.3	0.1	0.4	21.5	18.8	24.3
	Voice	Adults	12	2.1	0.5	1.2	22.8	3	556.8
		Children	37	6.5	1.4	4.5	56	4.5	1020
	Others (e.g., musical instrument)		15	2.6	0.6	1.4	61.8	8.3	428.5
	Sub-total		*77*	*13.5*					
Structure-borne sound source	Heavyweight impact	Adults' walking	65	11.4	2.5	4.1	18.4	1.3	302
		Children's running	82	14.3	3.2	7.4	32	3	1683
		Children's jumping	12	2.1	0.5	1.1	5.4	3	16
	Lightweight impact	Movement of furniture	159	27.8	6.1	8.3	6	1.3	212.5
		Dropping small items	99	17.3	3.8	5.1	5	1.3	82.5
		Door banging	41	7.2	1.6	1.7	3.3	1.5	4.75
		Scraping of small items	16	2.8	0.6	1.3	50.5	5	256.3
		Plumbing system	13	2.3	0.5	1.1	108	45.8	314.5
		Hammering	8	1.4	0.3	1.6	43.4	28.3	110
	Sub-total		*495*	*86.5*					
	Total		*572*	*100*					

units on the same floor and hallway. The majority of the noise sources were coming from the upstairs. In particular, all the heavyweight and lightweight impact sounds were generated by the residents above except for the door banging. In total, 17 of 41 door banging sounds (41.5%) came from the hallway and the neighbours on the same floor. Therefore, it was assumed that the inside noise levels were dominated by the structure-borne noises from upstairs. However, it was not possible to identify where the airborne sounds came from by listening to the recordings in the present study.

Durations of each noise source are also described in Table 3. The lengths of each noise source are quite different. The length of door banging was very short (median = 3.3 s), whereas noise from the plumbing system had a long duration (median = 108.0 s). Other sources such as musical instruments were found to have the largest duration. Among the structure-borne noise sources, the longest noise event was children's running at 1683 s.

Fig. 1 shows the number of occurrences for day, evening, and night across noise sources. It was found that the majority of noise events occurred during the daytime. This was mainly because the period of daytime is the longest, and the activities of the neighbours are most active at this time. For instance, movement of furniture, dropping small items, and children's running were dominant in the daytime. The number of occurrences of movements of furniture was the largest during the day, but they were also observed during the evening and night. In particular, the noise events that occurred by movement of furniture consisted of various movements noise events of furniture (e.g., scraping noises of table or chairs, impact noises of chairs etc.) while most of the events at night were shorter impact noises of chairs. The noise from the movement of furniture also lasted two times longer during the day time than night.

Four major noise sources most frequently heard accounting for 75.8% of all noise events were chosen to be investigated: (1) adults' walking, (2) children's running, (3) movement of furniture, and (4) dropping of small items. Fig. 2 represents the number of occurrences of four sources across time of day at an interval of one hour. The adults' walking mostly occurred during the daytime, in particular it was the most frequently occurring between 07:00 and 10:00. This maybe because adults' activities are dominant because

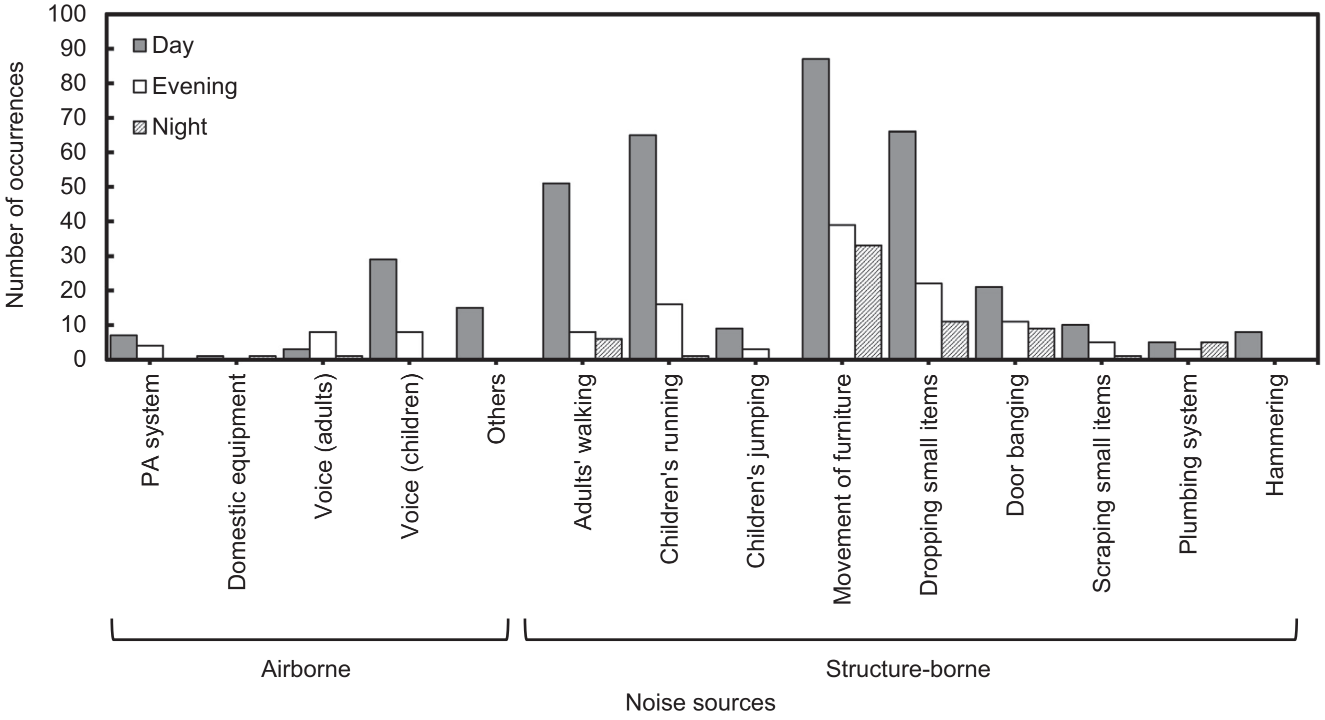


Fig. 1. Noise sources as a function of number of occurrences.

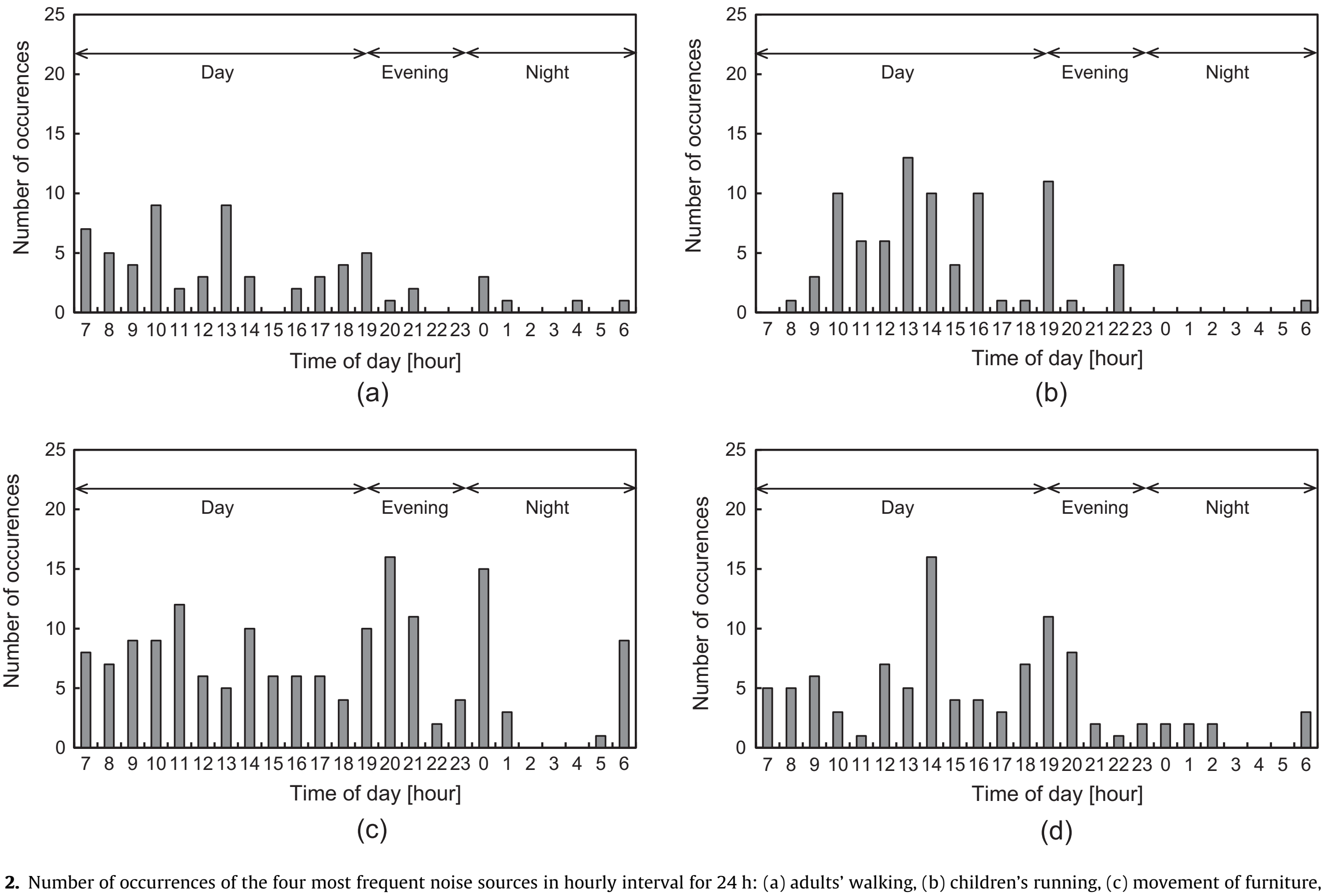


Fig. 2. Number of occurrences of the four most frequent noise sources in hourly interval for 24 h: (a) adults' walking, (b) children's running, (c) movement of furniture, and (d) dropping of small items.

it is time for getting ready to go to work, helping their children to go to school, or doing household chores. Movement of furniture (e.g., tables and chairs) also occurred frequently during that time which related to people's activities such as having breakfast or doing household chores. In addition, adults' walking was found to most frequently occur at around 13:00–14:00 during which other noise sources (children's running, movement of furniture, and dropping of small items) occurred frequently. It can be said that all of the four noises were closely related at that period, were primarily related to children's activities. In particular, it was identified that children's running noises during the afternoon occurred more frequently with scraping noises of chairs, and dropping or scraping noises of small objects. Movement of furniture had a relatively large number of occurrences in the evening (19:00–20:00) and at night (23:00–00:00). These noise events might be relevant to people's activities when coming back from work, for example, such as having dinner or resting.

Figs. 3 and 4 show the boxplots of the noise levels of each noise source in terms of the A-weighted sound exposure level (L_{AE}) and A-weighted maximum noise level (L_{AFmax}), respectively. Large variations of duration for noise sources indicate that L_{Aeq} is not appropriate to describe the noise levels of each source so the presentation of L_{AE} was adopted to describe noise levels of each source. Among the airborne noise sources, the noise from the PA system showed the highest median value in terms of L_{AE} followed by voice of children and other airborne noises. However, as listed in Table 3, the PA system was rarely identified throughout the measurement. Among the structure-borne sources, hammering and door banging produced the highest and lowest medians of L_{AE}, respectively. All the median values of adults' walking, children's jumping, movement of furniture, and dropping small items were similar and children's running and scraping small items had relatively higher median L_{AE} levels. Particularly, these two noise sources had higher median L_{AE} levels than other structure-borne noises (except hammering) since they lasted longer than the others and the time duration is applied to derive L_{AE} level. Children's running lasted 109.4 s on average (standard deviation = 263.6, median = 32.0) and the scraping noise of small items lasted 66.1 s on average (standard deviation = 76.7, median = 54.0). A similar tendency was observed in the boxplots of L_{AFmax} (Fig. 4). The PA system and hammering were the sources producing the highest L_{AFmax} from airborne and structure-borne noise sources but both were barely heard (6 and 4 events in total, respectively). Once the PA system and hammering were excluded, children's jumping and dropping small items were found to be have the higher L_{AFmax} than others followed by children's running and movement of furniture. In addition, airborne noise sources showed larger variations of median values than structure-borne sources.

3.3. Impact of slab thickness and number of noise events for different sources on noise levels

Fig. 5 shows the noise levels ($L_{Aeq,24\text{-}h}$, $L_{Aeq,Day}$, $L_{Aeq,Evening}$, and $L_{Aeq,Night}$) across the slab thickness. Contrary to expectations, the noise levels were not much changed with the increases of slab

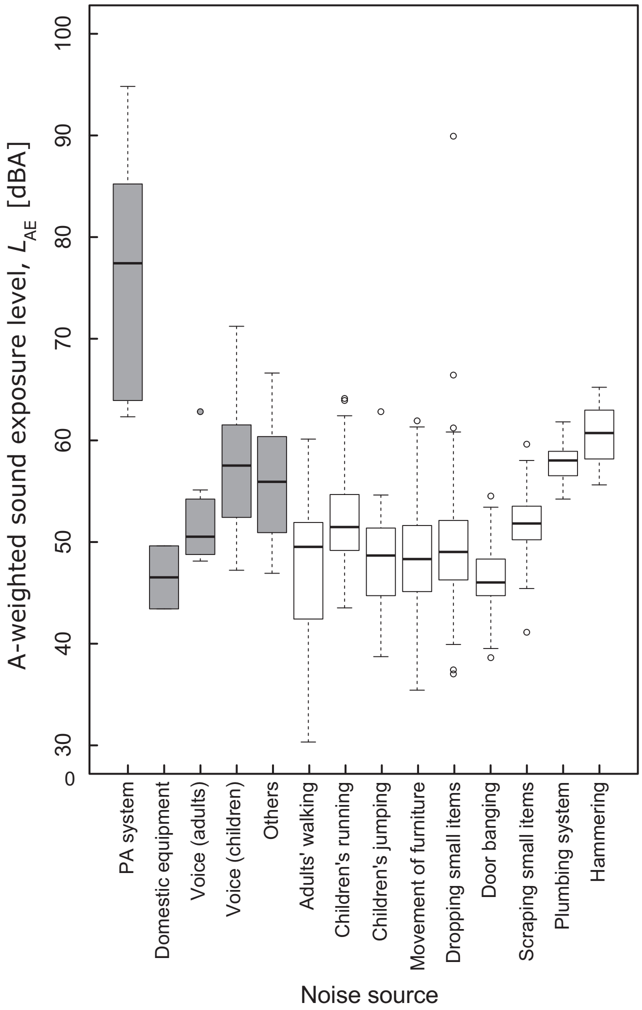


Fig. 3. Boxplots of A-weighted sound exposure levels (L_{AE}) for noise sources; airborne sound sources (grey boxes) and structure-borne sound sources (white boxes).

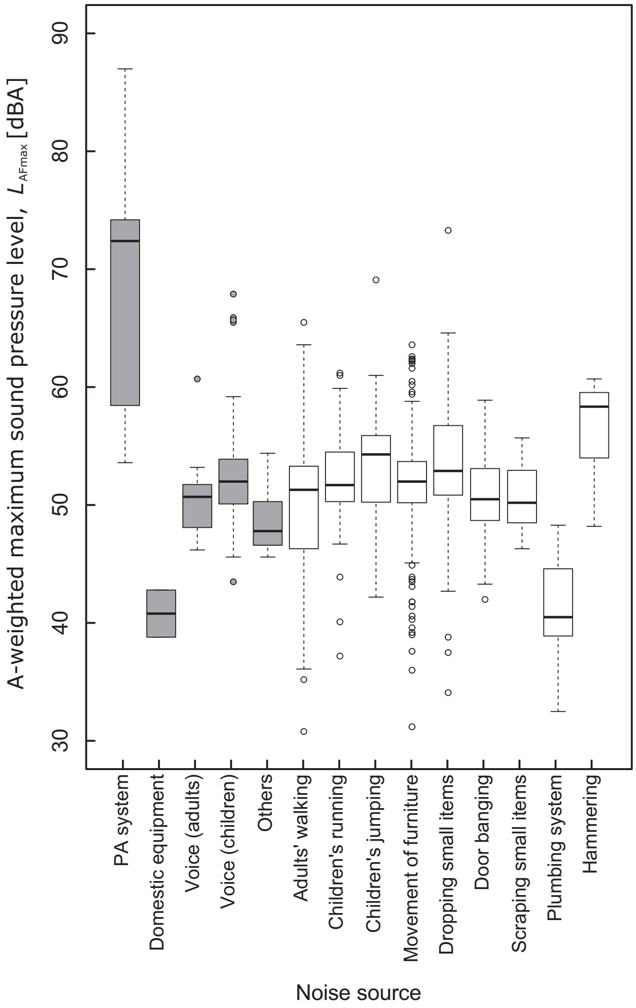


Fig. 4. Boxplots of A-weighted maximum sound pressure levels (L_{AFmax}) for noise source; airborne sound sources (grey boxes) and structure-borne sound sources (white boxes).

thickness. For example, the medians of $L_{Aeq,24\text{-}h}$ for 135 mm, 150 mm, 180, mm and 210 mm were 30.1, 30.4, 28.2 and 32.9 dBA, respectively. The 26 participating apartments were then classified into two groups according to their slab thickness (Group 1: 16 apartments with slab thicknesses of 135 mm and 150 mm; Group 2: 10 apartments with slab thicknesses of 180 mm and 210 mm) in order to investigate whether the increase in concrete slab thickness led to a reduction of noise events. Since the two sample sizes were unequal, the Mann-Whitney tests were conducted with noise levels (L_{AE} and L_{AFmax}), occurrence number, and length of noise events as dependent variables. The dependent variables only contained the data of structure-borne noises as the grouping factor (thicker slabs) would only affect noise events of structure-borne noises, not airborne noises. The median L_{AFmax} for Group 1 (53.1 dBA) was slightly higher than that of Group 2 (52.4 dBA) and there was no statistical significance found; the medians of L_{AE} for Groups 1 and 2 were 49.0 dBA and 49.1 dBA, respectively. The number of occurrences between Groups 1 and 2 were not significant, whereas Group 2 had significantly longer noise events than Group 1 ($p < 0.01$). These results indicate that better sound insulation performance due to increased slab thickness does not guarantee lower noise levels or fewer noise events in real environments because occurrence of neighbour noise is significantly influenced by neighbour's behaviours and activities.

In order to investigate whether indoor noise levels are affected by the number of occurrences and type of noise sources, correlation analyses were conducted. Noise levels (L_{Aeq} and L_{AFmax}) for 24 h, day, evening, and night were used. Meanwhile, the number of occurrences for all of the sources and number of occurrences for airborne, structure-borne, heavyweight impact, lightweight impact, and four major sources were introduced across different periods (24 h, day, evening, and night). The analysis was repeated for two groups, who were classified according to their slab thickness. The results of the correlation analysis are listed in Appendix B. Contrary to expectations, L_{Aeq} were not related with the number of occurrences for different types of sources. As shown in Fig. 6, this may be due to a couple of the outliers which showed opposite tendencies. For example, Site 1 showed the largest L_{Aeq} with just seven noise events for 24 h and L_{Aeq} of Site 14 is much lower than mean of 26 apartments although it has most number of noise events. The high noise level from Site 1 was caused by noise from a refrigerator in the kitchen. These results also revealed that indoor noise levels in apartment buildings are mainly influenced by neighbours' behaviours and activities. However, the exclusion of Sites and 1 and 14 resulted in some significant relationships between noise levels and noise sources. Specifically, L_{Aeq} for 24 h and during the daytime were significantly correlated with the number of occurrences. In contrast, L_{AFmax} had correlations with the number of occurrences for different types of sources. $L_{AFmax,24\text{-}h}$ and $L_{AFmax,Day}$ showed significant relationships with the number of occurrences of all sources, lightweight impact, and four major sources ($r = 0.40$, $r = 0.40$, and $r = 0.39$, respectively; $p < 0.05$ for all). Moreover, $L_{AFmax,Night}$ for the all participated sites and $L_{AFmax,Night}$ of Group 1 were found to have significant correlation with airborne noise ($r = 0.49$ and $r = 0.63$ respectively; $p < 0.05$).

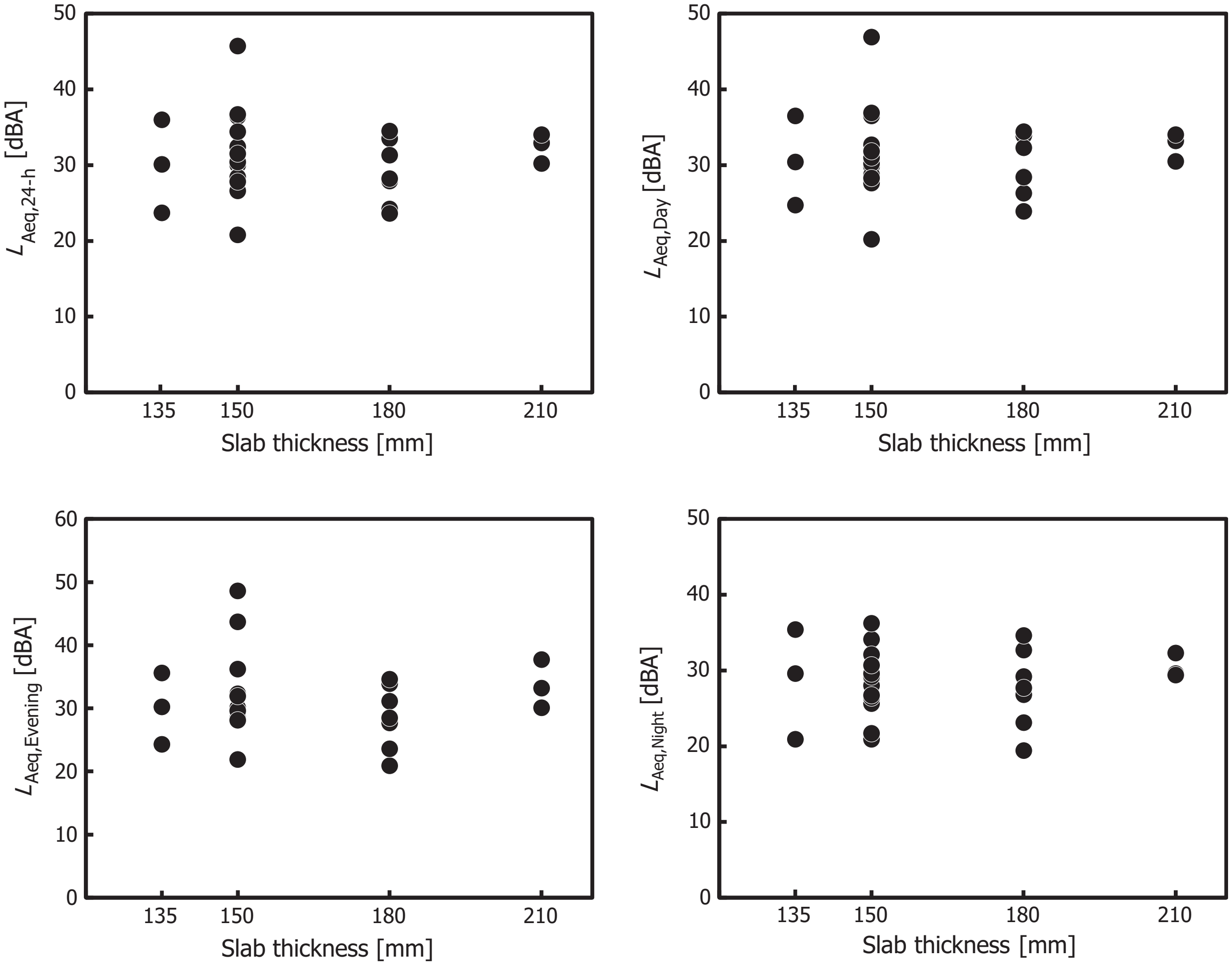
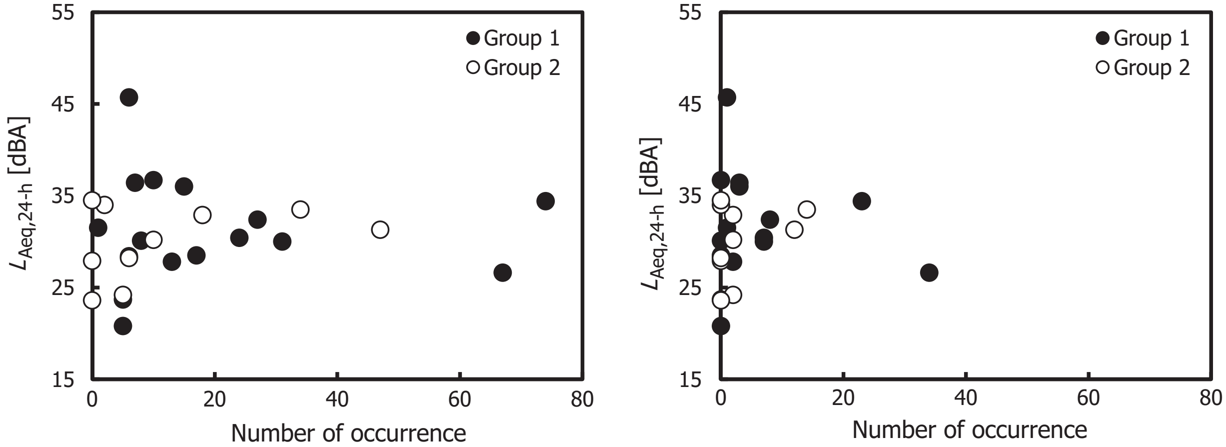
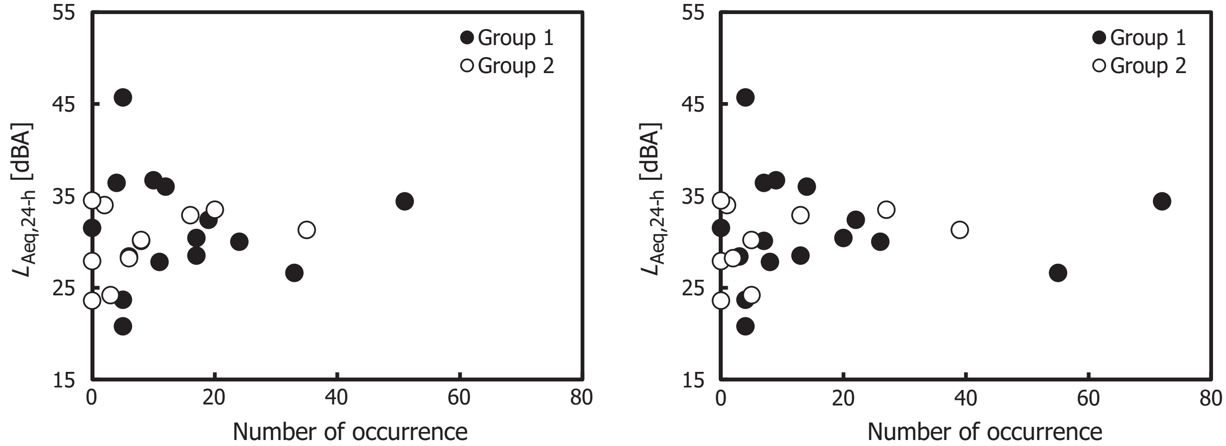


Fig. 5. Relationships between noise levels and slab thickness.



(a) Structure - borne sources

(b) Heavyweight impact sources



(c) Lightweight impact sources

(d) Major four sources

Fig. 6. Relationships between the number of occurrences of noise sources and $L_{Aeq,24\text{-}h}$ for Groups 1 and 2.

4. Discussions

The results of the overall noise levels showed that 20 of 26 apartments met the recommended daytime L_{Aeq} level of WHO guideline during the daytime. This does not indicate that the noise exposure levels are acceptable because the impact of outdoor noise sources on indoor noise levels was very limited because the windows were closed. The overall noise levels found in the present study had a good agreement with Jeon et al. [12] when they measured noise levels at empty apartments with closed windows. However, significant increase of indoor noise levels has been reported when properties are occupied or windows are opened so that outdoor noise is not controlled [7,12,13]. The noise levels might have increased if the current measurements were also conducted under natural ventilation conditions. During the night time, the levels of eight of the residential apartments showed an excess of the WHO limit value (30 dBA) in terms of L_{Aeq} for 8 h. The WHO guideline also recommends that L_{AFmax} should not exceed 45 dBA during the night. It was observed that only four residential apartments showed lower levels than this limit; thus, the residents in 22 apartments might have experienced sleep disturbance at night. Most of the L_{AFmax} at night were produced by movements of furniture between 05:00 and 07:00 or between 23:00 and 00:00. This finding is coincident with a previous study showing that some interviewees complained about noise coming from upstairs early in the morning and late night [20]. It was also found that the noise levels showed large variations across the measured sites. The L_{Aeq} for 24 h varied from 20.8 to 45.7 dBA, while the difference between the lowest and highest levels of L_{AFmax} was 40.7 dBA in the evening. This indicates that noise levels in apartments are significantly affected by neighbours and their activities.

The present study reported that the dominant noise sources in residential apartments are human walking, movement of furniture, and dropping of small items. This is consistent with the findings of a questionnaire survey on floor impact sound [21] reporting that children's running, dropping of items, and adult's walking were major noise sources. However, surveys in European countries reported quite different findings. A survey in the UK [22] showed that the most annoying neighbouring noise sources were airborne sources such as voices, dogs, and radio/television, whereas the percentage of neighbours footsteps and banging on walls or floors was less than 10%. A survey in the Netherlands also indicated that flushing sounds from a neighbour's toilets were the most commonly heard [23]. It was also found that playing pop music was the most annoying, followed by TV/radio and footsteps. The difference between the present study and the European studies could be attributed to the dwelling types of the respondents. For instance, in the UK study, the majority of the samples lived in semi-detached, detached, or terrace houses, whereas only 13% of them lived in either a flat or a maisonette [22]. A recent study on loudness and annoyance of neighbour noise in residential buildings also reported that subjective ratings varied across housing types [24].

Most studies on auditory experiments have applied the same noise level variations to different noise sources. For example, Jeon et al. [25] reported the annoyance ratings of two drainage (i.e., a bathtub draining and a flushed toilet) and two airborne noises (i.e., conversation and piano) with the same noise level variations. Ryu et al. [26] also investigated noise annoyance caused by five airborne sources (conversation, piano, ringing telephone, music, and TV). During the experiments, the same noise variation of 30 – 50 dBA was applied to all the noise sources. However, the present study revealed that variations of noise levels were different across noise sources. Therefore, this finding is beneficial for future study, in particular, auditory experiments using neighbour noises.

Previously, improvement of impact sound insulation of the floors has been reported with increases of concrete slabs [17,18]. However, these measurements were mostly conducted in laboratories using standard impact sources (i.e. impact ball and tapping machine), and noise levels in real situations have not been reported. The present study carried out the Mann-Whitney tests to compare the two groups of apartment with different slab thickness and found no significant difference between them. Therefore, a different approach could be considered to enhance acoustic comfort in apartments. For instance, subjective impression of building noise could be improved by dealing with non-acoustic factors. Recent studies reported a few non-acoustic factors affecting subjective reactions to floor impact noise such as the relationship with neighbours and negative attitude to neighbours as a sound source [27]. It was also reported that residents with higher intimacy with neighbours expressed less noise annoyance than others. This implies that noise annoyance could be reduced by using non-technical factors.

In the present study, 23 of the 26 measurements were conducted in warm seasons (spring, summer, and autumn). Under such conditions, the measured noise levels might be greater than the levels in winter because neighbours' windows are frequently opened. Additionally, 21 of the 26 measurements were performed during the school term so that the noises produced by children's activities were limited. Therefore, additional longitudinal measurements would be necessary in the future to cover all seasons and school holidays. The noise measurements were conducted only in living rooms in this study because noise complaints in living rooms are much more common than in bedrooms [21]. However, approximately 20% of neighbour noise was generated in bedrooms [8]; thus, the measurements in the bedrooms is a topic for future research and practice. Another limitation of this study is the lack of subjective data such as the noise annoyance ratings of the residents. It is quite common to report dose-response functions based on 24-h noise levels and subjective ratings in the environmental noise fields, but no one has attempted to show the relationship between subjective impressions and 24-h noise level by highlighting indoor noise, especially noise from neighbours. Therefore, it would be valuable to conduct both field measurements and a questionnaire survey in residential buildings.

5. Conclusion

The present study carried out noise measurements for 24 h at 26 empty apartments in South Korea. From the measurements, L_{Aeq} and L_{AFmax} for 24 h, day, evening, and night were analysed. Levels (L_{AE} and L_{AFmax}) and length of identified noise sources were then calculated. Twenty of 26 apartments met the recommended WHO guidelines during the daytime, whereas L_{AFmax} in 22 apartments were in excess of the recommended levels which could potentially cause sleep disturbance. Airborne noise sources included PA systems, domestic equipment, voices of adults, and voices of children. Structure-borne noise sources were more dominant than airborne noise sources, for example human footsteps (adults' walking, children's running and jumping), movement of furniture, dropping or scraping small items, doors banging, plumbing system, and hammering. It was found that adults' walking, children's running, movement of furniture, and dropping of small items were the most frequently occurring, accounting for approximately 80% of all the noise events. Among the airborne noise sources, children's voices were found to have relatively higher noise levels than other sources. Children's jumping was found to have the most severe structure-borne noise source in terms L_{AFmax}. Hammering showed the highest $L_{\mathrm{AE,}}$ followed by the scraping of small items and children's running. The present study could not find any statistically significant difference between the apartments with different slab thickness. Moreover, indoor noise levels were affected by neighbours' behaviours and daily activities rather than major noise sources and their number of occurrences. In the future, more preventative measurements, including both lightweight and heavyweight buildings, are required. Measurement of the noise levels in source room would also be useful to better understand noise levels from residents' activities.

Acknowledgement

This research was supported by a grant from a Strategic Research Project (A study on noise reduction solution for adjacency household in apartment house) funded by the Korea Institute of Construction Technology.

Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.apacoust.2017.01.012.

References

[1] Berglund B, Lindvall T, Schwela DH. Guidelines for community noise. Geneva, Switzerland: World Health Organization; 1999.
[2] Miedema HME. Relationship between exposure to multiple noise sources and noise annoyance. J Acoust Soc Am 2004;116:949–57.
[3] Clark C, Stansfeld SA. The effect of transportation noise on health and cognitive development: a review of recent evidence. Int J Compar Psychol 2007;20:145–58.
[4] Basner M, Babisch W, Davis A, Brink M, Clark C, Janssen S, et al. Auditory and non-auditory effects of noise on health. The Lancet 2014;383:1325–32.
[5] Babisch W. Cardiovascular effects of noise. Noise Health 2011;13:201–4.
[6] Maschke C, Niemann H. Health effects of annoyance induced by neighbour noise. Noise Control Eng J 2007;55:348–56.
[7] Pujol S, Berthillier M, Defrance J, Lardiès J, Petit R, Houot H, et al. Urban ambient outdoor and indoor noise exposure at home: a population-based study on schoolchildren. Appl Acoust 2012;73:741–50.
[8] Miedema HME, Vos H. Exposure-response relationships for transportation noise. J Acoust Soc Am 1998;104:3432–45.
[9] Miedema HME, Vos H. Noise annoyance from stationary sources: relationships with exposure metric day–evening–night level (DENL) and their confidence intervals. J Acoust Soc Am 2004;116:334–43.
[10] MacKenzie DJ, Galbrun L. Noise levels and noise sources in acute care hospital wards. Build Serv Eng Res Technol 2007;28:117–31.
[11] Kaarlela-Tuomaala A, Helenius R, Keskinen E, Hongisto V. Effects of acoustic environment on work in private office rooms and open-plan offices–longitudinal study during relocation. Ergonomics 2009;52:1423–44.
[12] Jeon JY, You J, Chang HY. Sound radiation and sound quality characteristics of refrigerator noise in real living environments. Appl Acoust 2007;68:1118–34.
[13] Lai ACK, Mui KW, Wong LT, Law LY. An evaluation model for indoor environmental quality (IEQ) acceptance in residential buildings. Energ Build 2009;41:930–6.
[14] Chan EHW, Lam KS, Wong WS. Evaluation on indoor environment quality of dense urban residential buildings. J Facil Manage 2008;6:245–65.
[15] Jeon JY, Hong JY, Kim SM, Lee PJ. Classification of heavy-weight floor impact sounds in multi-dwelling houses using an equal-appearing interval scale. Build Environ 2015;94:821–8.
[16] Criteria on the Authorization and Management of Block Structures for Floor Impact Sounds in Multi-dwelling Houses. Ministry of Land Infrastructure and Transportation, Republic of Korea; 2014.
[17] Hopkins C. Sound insulation. Routledge; 2007.

[18] Jeong JH, Jeong Y, Jeon JY. The effect of concrete slab thickness on the heavy-weight impact sound. In: Proceedings of INTER-NOISE 2005. Rio de Janeiro, Brazil; 2005.

[19] ISO 1996-2 Acoustics - Description, measurement and assessment of environmental noise, Part 2: Determination of environmental noise levels. International Organization for Standardization, Geneva, Switzerland; 2007.

[20] Park SH, Lee PJ, Yang KS. Perception and reaction to floor impact noise in apartment buildings: a qualitative approach. Acta Acust united Acust 2016;102:902–11.

[21] Jeong JH, Lee PJ, Jeon JY. Questionnaire survey on annoyance of floor impact sound. In: Proceedings of KSNVE Annual Autumn Conference. Korea; 2006.

[22] Defra. Survey of noise attitudes (SoNA) 2013, Report Ref: 47067932.NN1501. R1/02. AECOM Infrastructure & Environment UK Limited; 2015.

[23] van Dongen J. Noise Annoyance from Neighbours. In: Proceedings of INTER-NOISE 2001. Hague, Netherlands; 2001.

[24] Wang C, Si Y, Abdul-Rahman H, Wood LC. Noise annoyance and loudness: acoustic performance of residential buildings in tropics. Build Serv Eng Res Technol 2015;36:680–700.

[25] Jeon JY, Ryu JK, Lee PJ. A quantification model of overall dissatisfaction with indoor noise environment in residential buildings. Appl Acoust 2010;71:914–21.

[26] Ryu JK, Jeon JY. Influence of noise sensitivity on annoyance of indoor and outdoor noises in residential buildings. Appl Acoust 2011;72:336–40.

[27] Park SH, Lee PJ, Yang KS, Kim KW. Relationships between non-acoustic factors and subjective reactions to floor impact noise in apartment buildings. J Acoust Soc Am 2016;139:1158–67.

Building and Environment 116 (2017) 173–181

Contents lists available at ScienceDirect

Building and Environment

journal homepage: www.elsevier.com/locate/buildenv

Effects of floor impact noise on psychophysiological responses

Sang Hee Park, Pyoung Jik Lee*

Acoustics Research Unit, School of Architecture, University of Liverpool, Liverpool, UK

ARTICLE INFO

Article history:
Received 8 December 2016
Received in revised form
2 February 2017
Accepted 12 February 2017
Available online 16 February 2017

Keywords:
Floor impact noise
Noticeability
Annoyance
Psychophysiological response

ABSTRACT

The present study analysed the effects of floor impact noise on humans using both psychological and physiological methods. Floor impact noises caused by a standard impact source (i.e. impact ball) and five real impact sources (e.g., human footsteps and dropped objects) were recorded as sound stimuli. During the laboratory experiments, two factors that impact psychophysiological responses were considered: (1) types of impact sources (standard or real sources) and (2) the levels of floor impact noise ranging from 31.5 to 63 dBA in terms of A-weighted maximum sound pressure level (L_{AFmax}). Twenty-one normal-hearing subjects were then asked to judge the noticeability and annoyance caused by the floor impact noises. Meanwhile, the subjects' physiological responses (heart rate: HR, electrodermal activity: EDA, and respiration rate: RR) were monitored throughout the experiments. Noise annoyance and noticeability increased with increases in noise levels, the impact ball resulted in higher noticeability and annoyance ratings than real sources. All physiological measures varied significantly with noise exposure; HR decreased, whereas EDA and RR increased. The results show that the physiological responses were not affected by the type of noise source. In addition, the noise level was found to be significantly related to EDA and RR changes, whereas the relationship between the noise level and HR was not found to be significant.

1. Introduction

Several researchers have found non-auditory health effects of noise on people in laboratory and empirical studies [1,2]. Most research has attempted to analyse long-term health consequences of transportation noise such as aircraft or road traffic noise. Knipschild [3] argued that aircraft noise exposure is correlated with medical treatment for heart trouble and hypertension, higher use of cardiovascular drugs, and elevated blood pressure. Chronic exposure to aircraft or traffic noise increases physiological stress levels which can be measured through blood pressure or overnight epinephrine and norepinephrine [4,5]. Moreover, exposure to high traffic noise over long-term was reported to be correlated with the risk of coronary heart disease mortality [6]. Questionnaire survey studies also established a link between road traffic and aircraft noise and cardiovascular problems [7,8].

There is little evidence of health problems from noise in dwellings, although people spend most of their time in or around their home. In addition, questionnaire surveys or interviews are used more frequently than epidemiological methodology. Guite et al. [9] identified associations between dissatisfaction with the noise from neighbours and mental health risks. Another study using a questionnaire survey reported that people who perceived neighbour noise as a severe annoyance experienced higher health risks including cardiovascular disease [10]. Hongisto et al. [11] recently found that various neighbour noises had adverse effects on sleep quality; particularly, they reported that footstep noise was found to be one of the most disturbing impact noises from neighbours. More specifically, recent studies [12,13] focused on floor impact noise mainly produced by a neighbour's footsteps. Park et al. [13] proposed a link between noise perception (i.e. annoyance and disturbance) and noise reaction in a conceptual model based on semi-structured interviews. In particular, according to their model, annoyance induced by floor impact noise has a reciprocal relationship with mental or physical health complaints. This association was validated by a questionnaire survey, later indicating statistically significant relationships between disturbance, annoyance, and health complaints [12]. However, epidemiological evidence was not established to confirm any relationship between dwelling noise and health problems.

The sound pressure level has been identified as a crucial factor

---

* Corresponding author. Acoustics Research Unit, School of Architecture, University of Liverpool, Liverpool, L69 7ZN, UK.
E-mail address: P.J.Lee@liverpool.ac.uk (P.J. Lee).

http://dx.doi.org/10.1016/j.buildenv.2017.02.005

affecting health problems. Chronic expose to continuous noise at levels of at least 85 dBA was found to lead to higher blood pressure than individuals not exposed to noise [14]. It was also found that ambient traffic noise above 60 dBA had an impact on children's blood pressure and heart rate [15]. More recently, Babisch et al. [8] highlighted a significant association between aircraft noise and hypertension, which was stronger in more irritated people. Basner et al. [16] found a positive relationship between increasing noise levels and the risk of hypertension, strokes, and ischaemic heart diseases including myocardial infarction. Based on the relationships between noise levels and health issues, the World Health Organisation (WHO) proposed guidelines on noise levels in built environments to avoid damaging health effects [17]. The most frequently used approach to the study of the perception of noise is the use of questionnaires. However, self-reporting measures have some disadvantages; for example, some people may be less sensitive to small changes in stimuli than others and they may also tend to answer in socially desirable ways or in such a way that they would support the researcher's hypothesis. In contrast, physiological measurements are not controlled by the subjects but are triggered by the body, so that they can be regarded as objective measures. Therefore, the use of physiological measurements, in addition to questionnaires, would be beneficial to the study of the effects of noise on human and a number of studies have investigated the effects of noise on human using physiological measurements [18–21]. Despite a number of studies that reported the impact of noise levels on people's health, none have dealt with noise inside dwellings from neighbours, and in particular, floor impact noise. Therefore, it is necessary to explore the physiological responses to floor impact noise by measuring people's physiological data. The physiological measurements injunction with subjective ratings could provide further scientific evidence of floor impact noise on people.

Most studies on floor impact noise have used standard impact sources to create noise stimuli (e.g., tapping machine and impact ball). In particular, an impact ball has been used frequently in laboratory experiments [22,23] based on the physical similarities of an impact ball and humans. It was also reported that subjective perceptions of the impact ball are more similar to humans than other standard impact sources such as bang machine [23]. However, it remains unclear whether the physiological responses to a standard impact source are similar to those created by real sources.

This study aims to examine the psychophysiological responses to floor impact noise through laboratory experiments using three simple physiological measures (heart rate, electrodermal activity, and respiration rate). The experiments were used to examine the relationships between noise levels, source types, and psychophysiological responses, as well as to investigate differences in psychophysiological responses between a standard impact source and real sources.

2. Methods

2.1. Noise stimuli

Noise recordings were conducted in a test building which was designed to simulate the living rooms of residential buildings in Korea. Background noise level inside the test building was approximately 25 dBA. The floor layer of the building consisted of a 210 mm thick concrete slab, a 30 mm thick resilient material, a 40 mm thick lightweight concrete, and 40 mm thick mortar. All the room were furnished and wooden flooring was installed as a finishing material. The rooms were rectangular (4.5 m × 3.5 m) and the volume was around 38 m^3. Noise stimuli were recorded binaurally through a head and torso simulator (Brüel & Kjær Type 4100). The head and torso simulator was positioned on the sofa of the receiving room and impact sources were dropped near the centre of the source room floor. Diotic stimuli were made using only the left channel signals of the binaural recordings, and were then presented to the subjects in the laboratory experiment to avoid the effects of spatial characteristics on perception [24]. The whole sound reproduction system was validated by comparing reproduced sounds with recorded sounds. The reproduced sounds were recorded at the point of the subject's ear using a head and torso simulator in an audiometric booth. The frequency response of the reproduced sound was almost identical to the recorded sound in the test building within 3 dB (octave band levels, 63–2000 Hz). However, a minor difference was found at 31.5 Hz because the frequency response of the loudspeaker was not flat below 50 Hz.

A total of six different noise sources were used to represent a majority of the impact noises in apartment buildings [25]. Five real sources were used with a standard heavyweight impact source (i.e. impact ball) adopted in ISO 10140-5:2010 Annex F [26]. The real sources were classified into two groups based on their physical characteristics; 1) heavyweight impact sources and 2) lightweight impact sources. The heavyweight impact sources included human footsteps, such as an adult walking barefoot, a child running and jumping barefoot, while lightweight impact sources were the dropping of a toy (0.5 kg) and the scraping of a chair. A male adult subject with a weight of 70.1 kg and a height of 170.6 cm and a seven years old child with a weight of 24.1 kg were chosen as general walkers. The dropping height of the impact ball and the toy was 1 m. The frequency characteristics of the stimuli are presented in Fig. 1. All of the stimuli have similar frequency characteristics with dominant sound pressure levels at low frequencies, especially at 63 Hz and 125 Hz. Temporal features of the stimuli were also analysed in terms of L_{10}, L_{50} and L_{90} and A-weighted equivalent sound pressure level (L_{Aeq}) and A-weighted maximum sound pressure level (L_{AFmax}), which was calculated using the Fast time constant. L_{10}, L_{50} and L_{90} describe the level exceeded for 10, 50, and 90% of the measuring period. As listed in Table 1, the sound climate (L_{10} - L_{90}) values for all noises were greater than 10 dBA, while the

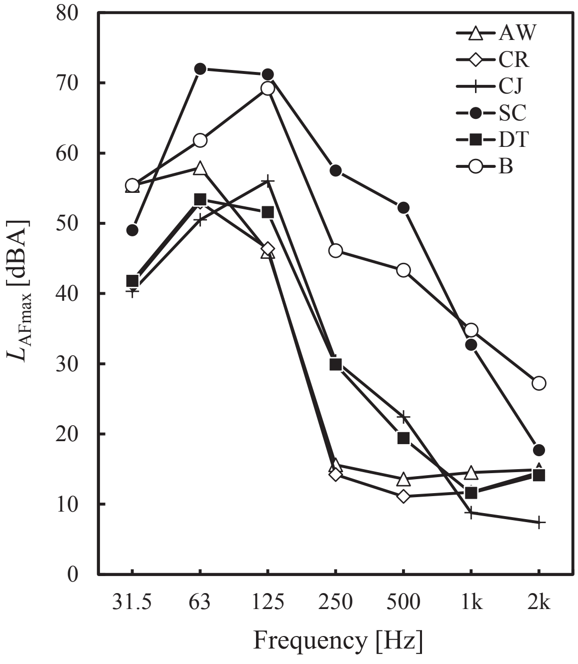


Fig. 1. Frequency characteristics of noise stimuli (AW: adult walking, CR: child running, CJ: child jumping, SC: scraping of a chair, DT: dropping of a toy, and B: impact ball).

Table 1
A-weighted equivalent sound pressure levels (L_{Aeq}), A-weighted maximum sound pressure levels (L_{AFmax}), and percentile sound pressure levels for recorded noises [dBA].

Sources		L_{Aeq}	L_{AFmax}	L_{10}	L_{50}	L_{90}
Real	Adult walking	33.1	46.3	37.2	22.7	21.7
	Child running	31.1	46.2	33.1	24.9	21.5
	Child jumping	37.5	53.8	36.4	12.2	11.6
	Dropping of a toy	35.1	50.0	37.7	21.5	21.2
	Scraping of a chair	55.9	65.0	60.7	50.3	22.6
Standard	Impact ball	51.3	64.9	52.1	23.8	21.7

scraping of a chair produced 38.1 dB difference between L_{10} and L_{90}.

Park et al. [25] reported that the sound pressure levels of major sources ranged from 30 to 65 dBA in residential buildings in terms of L_{AFmax}. Therefore, as shown in Table 2, L_{AFmax} levels of the stimuli were adjusted to cover ranges between 31.5 and 63 dBA in 3.5 dBA intervals without spectral adjustments. Each real source had different level variations based on the previous finding [25]. The noises produced by an adult's walking and a child's running ranged from 31.5 to 45.5 dBA, while the noises from a child's jumping had a variation from 38.5 to 63.0 dBA. The dropping of a toy had a quite minor variation from 42.0 to 49.0 dBA, while the noise level of a chair scraping varied from 49.0 to 63.0 dBA. Contrary to the real sources, the noise induced by the impact ball was adjusted to cover a whole range from 31.5 to 63.0 dBA.

2.2. Experimental design

The experiment consisted of five sessions. As outlined in Table 3, four of the five sessions (Sessions 1–4) were designed to evaluate psychophysiological responses. Specifically, it was hypothesised that noise level and the types of impact source might have an impact on psychophysiological responses. In order to investigate the effect of noise level on psychophysiological responses, the noise levels of each source varied from 31.5 to 63.0 dBA. Sessions 1–4 lasted for around 15 min each and each session included 10 or 11 noise stimuli. A session duration of 15 min was chosen to avoid fatigue effects and loss of concentration. Sessions 1–4 had varying noise levels depending on the noise sources presented in the session assuming that different noise exposure levels of each session might affect noise annoyance. Session 1 and Session 4 covered the entire range of sound pressure levels (L_{AFmax}) from 31.5 to 63.0 dBA, whereas the maximum L_{AFmax} of stimuli presented in Sessions 2 and 3 were 52.5 and 42.0 dBA, respectively. As a result, the subjects were exposed to quite a wide range of levels in each session. The A-weighted sound exposure levels (L_{AE}) of Sessions 1–4, which are the equivalent sound levels during the event normalised to a period of 1 s, ranged from 38.8 to 49.7 dBA. In order to determine whether the types of the impact source affect psychophysiological responses, Sessions 1–3 included real impact sources and the standard impact source was presented in Session 4. Sessions 1-4 adopted noticeability and annoyance in each session as psychological measures; however, annoyance assessment of each stimulus was not available due to other tasks. Therefore, Session 5 was designed to analyse the noise annoyance of each stimulus caused by both standard and real sources. The duration of Session 5 was approximately 7 min, shorter than the duration of the other sessions and the noise level of the stimuli covered the whole range of the sound pressure level from 31.5 to 63.0 dBA.

Park et al. [25] reported that the medians of the length of noise events were quite different across types of noise sources based on the field recordings in apartment buildings. Lightweight impact sources such as movement of furniture and dropping small items lasted for less than 10 s, whereas the durations of adults walking and children's jumping were 18.4 and 32 s, respectively. Therefore, in Sessions 1–4, all of the stimuli lasted for 23 s to represent human footsteps in real buildings [25]. All of the stimuli were spaced at equal intervals and each stimulus was separated by 50 s of silence. For physiological measurements, the first and last 2-min silence periods were allocated in each session for resting time. On the other hand, the duration of each noise was 8 s in Session 5 because it aimed to evaluate the noise annoyance of each stimulus. It was assumed that there would be no significant difference between the noise annoyance ratings of stimuli with different durations [27].

In each session, the stimuli were randomly presented via a loudspeaker (Fostex PM-1 MKII) to avoid order effects. An ambient noise was presented throughout the experiment, emanating from a single loudspeaker (Fostex PM-1 MKII) located in front of the listener. A 3-min interval was given after each session not just to avoid any possible carryover effects between sessions but also to give the subjects time to rate the annoyance of each session, to ensure the subjects were comfortable inside the booth, and to check that the electrodes were attached well. The ambient noise was equalised to have a spectrum shape of noise criterion curve (NC-35) to mimic typical ventilation noise.

Table 2
A-weighted maximum sound pressure levels (L_{AFmax}) of noise stimuli.

Sources		L_{AFmax} [dBA]									
		31.5	35.0	38.5	42.0	45.5	49.0	52.5	56.0	59.5	63.0
Real	Adult walking	■	■	■	■	■					
	Child running	■	■	■	■	■					
	Child jumping			■	■	■	■	■	■	■	■
	Dropping of a toy				■	■	■				
	Scraping of a chair						■	■	■	■	■
Standard	Impact ball	■	■	■	■	■	■	■	■	■	■

Table 3
Outline of the laboratory experiment.

Sessions		1	2	3	4	5
Range of L_{AFmax} [dBA]		31.5 ~ 63.0	31.5 ~ 52.5	31.5 ~ 42.0	31.5 ~ 63.0	35.0 ~ 63.0
Noise stimuli	Type	Real	Real	Real	Standard	Real/standard
	Number	11	10	10	10	33
	Source*	AW CR CJ SC DT	AW CR CJ SC DT	AW CR CJ DT	B	AW CR CJ SC DT B
L_{AE} of the session [dBA]		49.7	43.1	38.8	46.8	52.8
Duration of the session [min]		16.6	15.3	15.3	15.3	7.3
Measurements	Physiological response	HR, EDA, RR	HR, EDA, RR	HR, EDA, RR	HR, EDA, RR	-
	Psychological response	Noticeability / Annoyance of the session	Noticeability / Annoyance of the session	Noticeability / Annoyance of the session	Noticeability / Annoyance of the session	Annoyance of each stimulus

*AW: adult walking, CR: child running, CJ: child jumping, SC: scraping of a chair, DT: dropping of a toy, and B: impact ball

2.3. Measurements of psychophysiological responses

2.3.1. Psychological responses

It has been reported that the perception of noise is determined by short notice-events [28–30]. Therefore, in the present study, the psychological responses to floor impact noise were assessed in terms of noticeability and annoyance. As shown in Table 3, the noticeability of noise events was evaluated in Sessions 1–4, and the subjects were requested to press a response button whenever they heard a floor impact noise during the experiment. The subjects were also asked to rate their annoyance at the noise exposure using an 11-point scale (0 = “Not at all” to 10 = “Extremely”) at the end of Sessions 1–4. Annoyance generated by short-term noise exposure was evaluated in Session 5. In contrast to Sessions 1–4, the subjects evaluated the noise annoyance of each noise stimulus using a magnitude estimation technique. A reference noise with 42 dBA was presented to the subjects before they were exposed to each noise stimulus. They then rated the noise annoyance of the stimulus on the basis that annoyance caused by the reference noise was rated as 100. A training session for the magnitude estimation was used to help subjects become acquainted with this method.

2.3.2. Physiological responses

In the current study, three simple physiological measures were used: 1) heart rate (HR) expressed in beats per minute (BPM), 2) electrodermal activity (EDA) expressed in micro Siemens (μS), and 3) respiration rate (RR) expressed in beats per minute (BPM). All of the physiological responses were recorded on a laptop computer using a MP 150 WSW digital acquisition system (BIOPAC Systems) and were analysed using AcqKnowledge 4.4 (BIOPAC Systems). Two wireless amplifiers were placed under the desk where the subjects were seated. These amplifiers received all of the data from the recording units via the operation of a Bluetooth transmitting mode. The HR was gathered from the raw data of electrocardiographs (ECG), while the ECG was measured through electrodes attached to each subject's right wrist and both ankles. The EDA was measured using electrodes attached to the subjects' index finger and the middle finger of the right hand. The RR was computed from the raw respiration data, which was measured through a respiration transducer belt worn around the chest. The respiration transducer belt records respiration data by measuring the changes in thoracic circumference that occur when an individual breathes.

It is known that there is a delay in the onset of stimulus-evoked physiological activity [31]. As the present study only focuses on analysing the response changes following such delays, the physiological data in noise exposure was collected for the last 18 s, excluding the first 5 s immediately after each stimulus delivery [32,33]. In addition, 50 s was designated before each noise stimulus as a baseline for comparison with the next noise stimulus. The subject's responses varied during baseline and noise exposure; therefore, the percentage change (%) was calculated to adjust all the different values [34]. The percentage change was defined as the percentage of change from the baseline to noise exposure.

2.4. Procedure

The subjects were asked to refrain from staying up all night or drinking alcohol before bedtime on the day before the experiment, and to avoid consuming caffeinated drinks on the day of the experiment. The experiments were conducted in an audiometric booth where the background noise level was set at approximately 25 dBA. To ensure precise measurements, all the electrodes were initially attached to the subject's body (right wrist, two fingers of the right hand, and both ankles) to make sure that the gel on each electrode was fully absorbed into the skin before the experiment commenced. The subjects were asked to sit facing two loudspeakers in front of them. A training session was carried out before the sessions began. The training session was 3 min long and consisted of noises produced by both real and standard impact sources. The subjects attended the five sessions on two different dates and the sessions were random. Given that resting and reading has a strong correlation with perceiving noise annoyance [35], the subjects were asked to read an e-book on a tablet placed in front of them and asked to imagine that they were resting in their own home.

2.5. Subjects

Twenty-one subjects (8 males and 13 females) aged between 18 and 42 (mean = 29.5, standard deviation = 6.6) took part in the experiment. None of the subjects reported hearing disabilities. Seven subjects were married and six of them had a child or several children. Of these subjects, 13 reported that they had experienced being exposed to noises from their upstairs neighbours or were experiencing issues with noise in their current dwelling.

2.6. Statistical analysis

Statistical analyses were performed using SPSS for Windows (version 22.0, SPSS Inc. Chicago, IL). Differences in the mean values were tested with the Wilcoxon signed-rank test to estimate the significance of the differences in the psychophysiological responses between real and standard impact sources. Repeated measures analysis of variance (ANOVA) was also used to investigate the effects of noise level and source type on the physiological responses. Greenhouse–Geisser adjusted degrees of freedom were used for tests of within-subject effects. In this study, p values less than 5% ($p < 0.05$) were considered statistically significant.

3. Results

3.1. Psychological responses

Fig. 2 shows the noticeability of floor impact sounds as a function of L_{AFmax} across the different sources. For both noise sources, the noticeability increased as the sound pressure level increased. Two regression lines show the difference between the standard impact source and real impact source. The solid and dotted lines represent the noticeability of the standard source and the real sources (AW, CR, CJ, SC, and DT), respectively. Some results of the real sources are invisible because they overlap with those of the standard impact source. For instance, the ratings of DT overlap with B at 42 dBA, while CJ and DT also overlap with B at 45.5 dBA. The correlation between noticeability and L_{AFmax} was found to be statistically significant ($r = 0.62$, $p < 0.01$ for whole stimuli, $r = 0.64$, $p < 0.01$ for standard source, and $r = 0.61$, $p < 0.01$ for real sources). Around 60% of the subjects noticed the noises at 38.5 dBA and the noticeability reached 100% when the levels were above 49 dBA. Differences between the two impact sources were identified between 35 and 45.5 dBA, and the differences gradually increased as the noise level increased. However, statistically significant differences between the sources were found at two levels (at 42.0 dBA, $p < 0.01$ and at 49 dBA, $p < 0.05$). It was found that the noticeability of the real impact sources also varied at the same levels according to the source type. For example, for noises at 38.5 dBA, the noticeability ranged from 52.4% to 71.4%. This variation may be the result of differences in temporal and spectral characteristics of the noises.

Fig. 3(a) shows the mean magnitude estimates of noise annoyance for each noise stimulus obtained from Session 5 using magnitude estimation, while Fig. 3(b) represents the mean annoyance ratings from Sessions 1–4. As shown in Fig. 3(a), the mean magnitude estimates of noise annoyance increased as the noise level increased for both standard and real sources. It was also observed that standard deviations also increased along with increase of noise level for both sources. The mean magnitude estimates of the standard impact source were consistently higher than those of the real impact sources and the statistical analysis confirms that the differences between the two sources were statistically significant at all levels. The correlation coefficients between mean magnitude estimates (annoyance ratings) and L_{AFmax} were greater than 0.9 for both sources ($r = 0.95$, $p < 0.01$ for whole stimuli, $r = 0.93$, $p < 0.01$ for standard source and $r = 0.95$, $p < 0.01$ for real sources). A correlation analysis also highlighted that the annoyance ratings of each stimulus were highly correlated with noticeability for both sources ($r = 0.43$, $p < 0.01$ for standard source and $r = 0.47$, $p < 0.01$ for real sources).

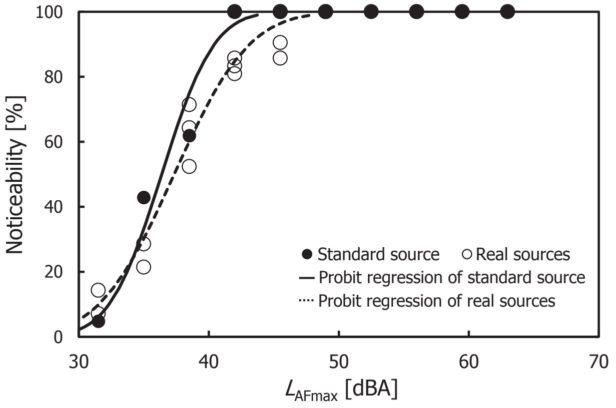
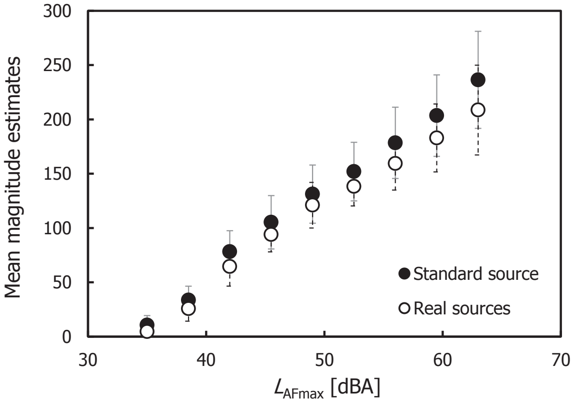
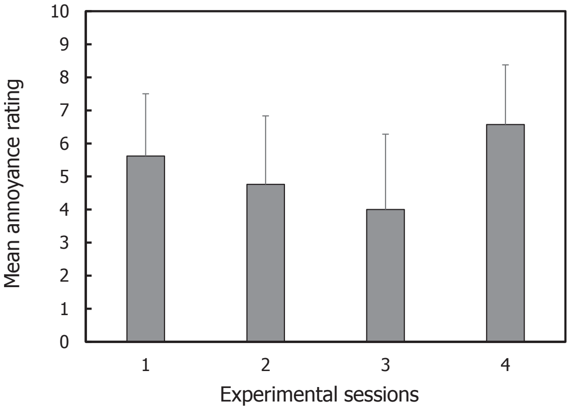


Fig. 2. Noticeability ratings for floor impact noise (●: standard impact source and ○: real impact sources) as a function of L_{AFmax}. Probit regression curves for standard and real impact sources are also presented.



(a)



(b)

Fig. 3. Mean magnitude estimates of noise annoyance for each noise stimulus (a) and mean annoyance ratings of Sessions 1–4 (b) with error bars indicating standard deviation.

As shown in Fig. 3(b), the mean annoyance ratings of each session varied slightly across the sessions. The Wilcoxon signed-rank tests revealed that the mean annoyance ratings of Sessions 1–4 were all significantly different ($p < 0.01$). Session 3 with the real impact sources recorded the lowest noise annoyance rating (mean = 4.0, standard deviation = 2.3) due to the lowest L_{AE}. The highest annoyance rating (mean = 6.6, standard deviation = 1.8) was recorded in Session 4 with the standard impact source. The rating of Session 1 with the highest L_{AE} was slightly lower than Session 4, indicating that the standard impact source resulted in greater annoyance than the real sources. This implies that noise annoyance ratings were affected by the source type as well as the noise exposure level.

3.2. *Physiological responses*

The results of the psychological assessments demonstrate that the subjects hardly noticed the noise and reported very low annoyance ratings while noise levels remained below 38.5 dBA. Thus, the noise stimuli at 31.5 and 35.0 dBA were excluded from analyses of the subjects' physiological responses. Changes in HR, EDA, and RR were averaged for Sessions 1–4 and the mean changes were then presented for the standard and real sources in Fig. 4. The mean changes are listed in Table 4 with medians and standard deviations. The mean HR decreased by more than 1% for both sources and the difference between the baseline and the noise exposure was statistically significant ($p < 0.05$). HR response to the standard source decreased slightly more than that of the real sources but there was no significant difference between the sources. EDA increased significantly due to noise exposure ($p < 0.05$). The mean EDA changes were more than 2% for the standard source and 1% for the real sources; the standard source resulted in a higher increase than the real sources but the difference between the two types of source was not statistically significant. Similarly, significant RR increases (more than 3% for both sources) were recorded when subjects listened to floor impact sounds ($p < 0.05$). The RR change of standard source was higher than that of real sources which can be interpreted as meaning that the subjects were more sensitive to the standard impact source; however, the two changes were not statistically significant.

Fig. 5 shows the mean changes of HR, EDA, and RR as a function of L_{AFmax}. Open circles indicate the results from real sources and filled circles represent the responses to the standard impact source. The mean changes are also summarised in Table 5 with medians and standard deviations. Repeated measures of ANOVA was used to estimate the significance of differences in physiological response changes across different source (standard or real sources) and noise levels (L_{AFmax}). Source types had no significant main effect on any of the physiological responses. However, the main effects from noise level were on EDA [F(4.348,86.953) = 4.251, ($p < 0.01$)] and RR [F(4.797,95.944) = 4.748, ($p < 0.01$)]. The interaction between source type and noise level had no significant impact on HR and EDA but influenced RR significantly [F(4.772,95.439) = 3.715, ($p < 0.01$)].

The findings of the correlation analysis show that, for the standard impact source, EDA and RR were influenced by L_{AFmax} ($r = 0.21$, $p < 0.01$ for EDA and $r = 0.31$, $p < 0.01$ for RR). For the real sources, EDA was correlated with L_{AFmax} ($r = 0.14$, $p < 0.01$); however, the relationship between HR and L_{AFmax} was not significant. Additional analysis was conducted to investigate whether the physiological response changes were influenced by psychological responses. As summarised in Table 6, noticeability for the standard impact source had impacts on EDA and RR ($r = 0.17$, $p < 0.05$ for EDA and $r = 0.41$, $p < 0.01$ for RR) and annoyance also correlated with EDA and RR ($r = 0.23$, $p < 0.01$ for EDA and $r = 0.17$, $p < 0.05$ for RR). In addition, annoyance to the real sources were correlated with EDA ($r = 0.13$, $p < 0.01$).

4. Discussion

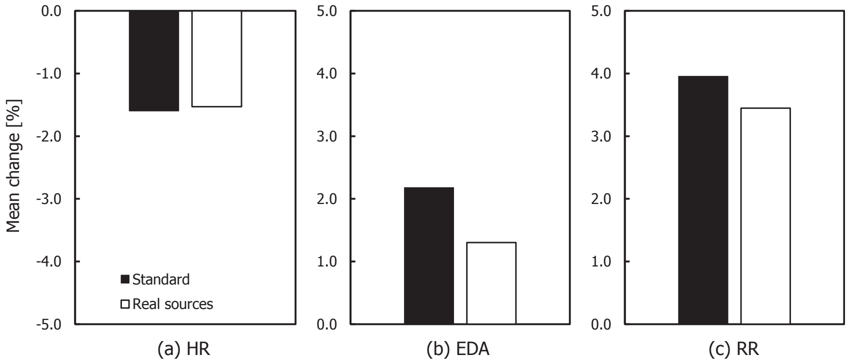
4.1. *Psychological evaluations of the floor impact sounds*

Previous research [28–30] has reported a strong relationship between the noticeability and sound pressure levels of outdoor noises. These studies have also suggested that noise annoyance ratings can be explained by noticeability or detectability. The present study expanded their findings to indoor dwelling noises that are impulsive and transient. In this study, noticeability of floor impact noise was influenced by noise level and noise annoyance ratings were highly correlated with noticeability. This indicates that floor impact noise, when heard in residential buildings, may have a significant impact on residents' subjective judgements.

The impact ball was found to have a similar physical characteristic to humans in terms of mechanical impedance and impact force [36]. The subjective impression of the impact ball sound was also similar to a human-made sound [23]. Based on these findings, the impact ball was introduced as a standard impact source in international standard to mimic human footsteps (ISO 10140-5:2010) [26]. However, the findings of the present study show that psychological responses to impact ball sounds differed significantly compared to sounds produced by real sources in terms of both noticeability and annoyance.

4.2. *Changes in physiological responses due to noise exposure*

Park *et al.* [13] previously developed a model suggesting the relationships between noise exposure, annoyance, and health complaints. Among them, the relationship between annoyance and



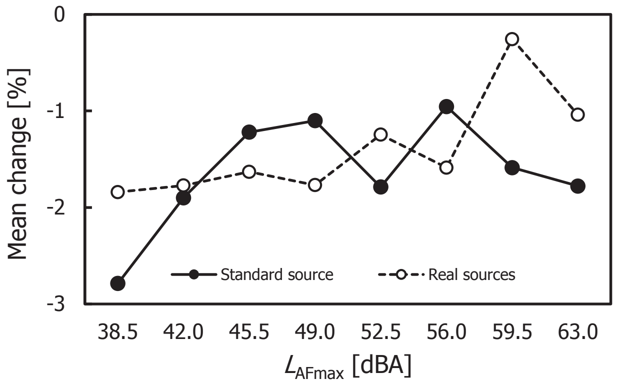
(a) HR (b) EDA (c) RR

Fig. 4. Mean changes of physiological responses during Sessions 1–4: (a) HR, (b) EDA, and (c) RR.

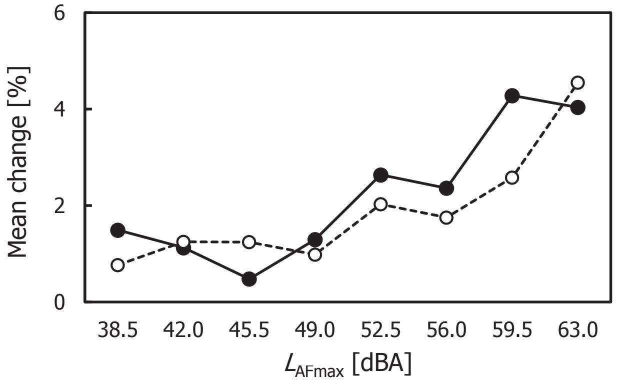
Table 4
Mean changes of physiological responses for standard impact source and real impact sources. Values in second and third rows represent medians and standard deviations.

		HR	EDA	RR
Standard impact source	Mean changes (%)	−1.60	2.18	3.95
	Median (%)	−1.37	0.54	4.05
	Std. deviation	0.02	0.04	0.03
Real impact sources	Mean changes (%)	−1.53	1.30	3.45
	Median (%)	−1.28	0.13	3.12
	Std. deviation	0.03	0.04	0.04

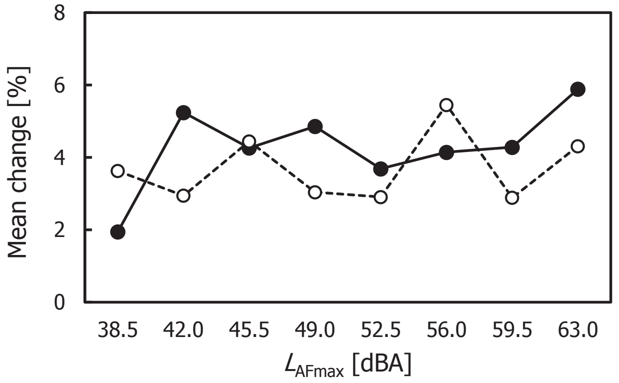
health complaints was validated via a questionnaire survey [12]. The findings from the present study provided evidence to confirm this relationship in laboratory experiments. This study found that the annoyance ratings of the standard source were correlated with EDA and RR and the annoyance of real sources were correlated with EDA. In addition, the present study revealed that noise level had key effects on the mean changes in EDA and RR. This implies that noise exposure might influence health problems as well as annoyance confirming the conclusion of a previous study [13] in which multiple relationships between noise exposure, perception, and health were suggested. An independent-samples T-test was used in order to assess whether there was any difference between the physiological responses of the subjects who had the past experience of being exposed to floor impact noise ($n = 13$) and those who had no past experience ($n = 8$). There was no significant difference between the HR and EDA of the two groups. However, there was a significant difference in the mean change of RR between those who had the past experience (mean = 3.7%, standard deviation = 0.04) and those who did not have any past experience (mean = 3.4%, standard deviation = 0.03); t (734) = −3.20, $p = 0.001$). This is in line with Park et al.'s [13] previous suggestion that having past experiences of noise exposure can affect health complaints. In addition, it was found that there was a significant difference in noticeability between those who had the past experience (mean = 77.3%, standard deviation = 0.42) and those who did not have any past experience (mean = 63.1%, standard deviation = 0.48); t (619) = −4.40, $p = 0.000$), whereas the differences in annoyance ratings between the groups were not significant.



(a) HR



(b) EDA



(c) RR

Fig. 5. Mean changes of physiological responses as a function of L_{AFmax}: (a) HR, (b) EDA, and (c) RR.

Lang et al. [37] proposed a model indicating the relationship between physiological responses and arousal intensity. According to this model, people's physiological responses to the stimuli can be classified into three stages: pre-encounter, post-encounter, and circa-strike. Circa-strike is the final stage, which involves active defense and thus aims to eliminate reactions to secondary, probe stimuli [37]. Before presentation of the stimuli, physiological responses such as HR and EDA are almost calm in the pre-encounter stage, while HR decreases and EDA increases with exposure to arousal stimuli during the post-encounter stage. The changes of HR and EDA occur because people's attention is oriented to stimuli [37,38]. While high arousal stimuli are presented, EDA keeps increasing, but HR changes its direction upward. A number of studies have confirmed the changes in HR and EDA in the post-encounter and circa-strike stages through laboratory experiments. Bradley et al. [18] found that 6-s arousing and unpleasant sounds led to significant HR deceleration. Similarly, Hume et al. [19] reported deceleration in HR during the presentation of 8-s sound clips. On the other hand, several studies [20,21] using highly arousing noise stimuli reported HR accelerations indicating the circa-strike stage. Gomez et al. [20] used 30-s noise stimuli varying from 52.2 to 77.5 dBA, while Holand et al. [21] presented 0.15-s noise at 110 dBA to the subjects. Regarding the changes of EDA, Tajadura-Jiménez et al. [39] found that unpleasant and arousing sounds resulted in the largest EDA increases. Reinhardt et al. [40] also reported a significant increase in EDA resulting from 5-min long noise exposures ranging from 78 to 93 dBA. In addition, EDA increases evoked by noise stimuli were observed in recent soundscape studies [41,42]. In the present study, HR decreased but EDA

Table 5
Mean changes of physiological responses at each noise level for standard impact source and real impact sources. Values in second and third rows represent medians and standard deviations.

		L_{AFmax} [dBA]							
		38.5	42.0	45.5	49.0	52.5	56.0	59.5	63.0
a) Standard impact source									
HR	Mean changes (%)	−2.79	−1.90	−1.22	−1.10	−1.79	−0.95	−1.59	−1.78
	Median (%)	−2.90	−1.89	−0.41	−0.86	−1.93	−0.76	−0.91	−1.75
	Std. deviation	0.03	0.03	0.03	0.02	0.01	0.01	0.02	0.02
EDA	Mean changes (%)	1.49	1.13	0.48	1.29	2.64	2.36	4.28	4.04
	Median (%)	0.10	0.54	−0.73	0.45	1.15	0.54	4.19	3.24
	Std. deviation	0.05	0.02	0.03	0.03	0.05	0.05	0.02	0.04
RR	Mean changes (%)	1.94	5.24	4.26	4.85	3.68	4.14	4.28	5.89
	Median (%)	1.71	5.37	3.89	4.97	3.28	4.05	4.22	5.57
	Std. deviation	0.04	0.02	0.04	0.03	0.03	0.01	0.01	0.02
b) Real impact sources									
HR	Mean changes (%)	−1.84	−1.77	−1.63	−1.77	−1.25	−1.59	−0.26	−1.04
	Median (%)	−1.47	−1.46	−0.68	−1.52	−0.86	−1.40	−0.16	−0.39
	Std. deviation	0.03	0.03	0.03	0.03	0.03	0.02	0.03	0.03
EDA	Mean changes (%)	0.77	1.25	1.24	0.99	2.03	1.75	2.58	4.55
	Median (%)	0.13	0.04	0.10	0.20	0.34	0.24	2.77	3.85
	Std. deviation	0.02	0.04	0.04	0.04	0.05	0.05	0.05	0.04
RR	Mean changes (%)	3.62	2.94	4.44	3.04	2.90	5.45	2.88	4.31
	Median (%)	3.65	2.28	4.43	2.55	2.70	5.57	2.33	4.69
	Std. deviation	0.03	0.04	0.04	0.04	0.02	0.03	0.03	0.03

increased due to noise exposure indicating that subjects were in a post-encounter stage rather than a circa-strike stage. This is because the noise levels presented in this study were not sufficient to lead to high arousal status and durations of noise exposure were quite short.

Our laboratory experiment also revealed that RR accelerated during noise exposure. This result is consistent with the findings of previous studies [19,20,43], in which experiences of arousal or emotions (e.g., anger and fear) lead to an increase of RR. Gomez et al. [20] found accelerated breathing with decreasing pleasantness using noises ranging from 52.2 to 76.7 dBA, while Gomez et al. [43] reported an association between arousal incurred by sounds and respiratory responses. Hume et al. [19] also found accelerated RR with man-made sound exposures [12,13].

4.3. Relationship between sound pressure level and physiological responses

A number of field and laboratory studies have addressed the associations between sound pressure levels and physiological responses. Several field studies have reported that physiological responses were influenced by the sound pressure levels of stimuli. Regecová et al. [15] found that children living in areas with high levels of traffic noise (>60 dBA) showed lower HR than those in quiet areas, while Stansfeld [44] reported a positive correlation between sound pressure levels and EDA. Zahr et al. [45] also found significant respiratory changes in infants when sound pressure levels were reduced by wearing earmuffs. Moreover, Babisch et al. [8] identified significant relationships between transportation noise levels and hypertension. However, a recent laboratory study [19] came to the opposite conclusion; the sound pressure levels of 8 s stimuli were not correlated with physiological responses (heart rate, respiratory rate, and forehead electromyography level). The present study showed that sound pressure levels were correlated with EDA and RR, whereas the relationships between HR and noise levels were insignificant. The inconsistency between field and laboratory studies may be the result of different durations of noise exposure. Contrary to field studies dealing with longer noise exposure [8,15,45], Hume et al. [19] and the present study focused on short noise effects on physiological responses.

Table 6
Correlation coefficients between the mean changes of physiological responses, annoyance, noticeability, and sound pressure level (L_{AFmax}) ($^{**}p < 0.01$;$^{*}p < 0.05$).

	Annoyance	Noticeability	L_{AFmax}
a) Standard impact source			
HR	0.13	−0.12	0.03
EDA	0.23^{**}	0.17^{*}	0.21^{**}
RR	0.17^{*}	0.41^{**}	0.31^{**}
b) Real impact sources			
HR	0.06	−0.03	0.02
EDA	0.13^{**}	0.02	0.14^{**}
RR	0.01	0.04	0.05

4.4. Future research needs

There are several points to be improved upon in the design of future psychophysiological studies of floor impact noise. First, as discussed in the previous section, different changes in HR have been found in different studies. As most of them used short noise stimuli (<30 s), further investigation using longer stimuli would be helpful for understanding long-term changes of physiological responses including HR. Second, noise sensitivity has a significant influence on the prevalence of noise annoyance [46,47]. In particular, Öhrström et al. [47] stated that noise annoyance is affected not just by general neurophysiological sensitivity but also subjectively reported noise sensitivity. Future studies could focus on potential physiological indices that can represent individual noise sensitivity ratings. Third, this study measured three simple physiological responses (HR, EDA, and RR); however, additional measurements of other physiological data (e.g., respiratory sinus arrhythmia: RSA) would also be beneficial to gain new or broader insights into the adverse effects of floor impact noise. Fourth, the loudspeakers could be located above the subjects to simulate the sound from an upper floor and a subwoofer could be used to reproduce low frequency sounds below 50 Hz.

5. Conclusion

This study investigated subjects' psychological responses (noticeability and annoyance) and physiological responses (HR, EDA, and RR) to floor impact noises produced by both standard and real sources. The findings show that noticeability increased with higher sound pressure levels, and noise induced by the standard impact source led to higher noticeability than the real impact sources. Noise annoyance ratings also increased as sound pressure levels were increased. The annoyance ratings of the standard impact source were also greater than the real sources. The physiological responses to noise stimuli were calculated from the experiment. Deceleration in HR, increases in EDA and RR were identified during the noise exposure, demonstrating that the noise stimuli influenced the arousal status of the subjects. The physiological responses were not affected by the type of source (standard or real impact source), whereas the sound pressure level had a major impact on EDA and RR. In addition, annoyance and noticeability for real sources were correlated with EDA and RR, whereas psychological responses to the standard impact source showed no relationship with any physiological measure. Future research is required to further understand the long-term effects of floor impact noise on physiological responses by considering subjects' personal factors such as noise sensitivity.

Acknowledgement

This research was supported by a grant from a Strategic Research Project (A study on noise reduction solution for adjacency household in apartment house) funded by the Korea Institute of Civil Engineering and Building Technology.

References

[1] W. Passchier-Vermeer, W.F. Passchier, Noise exposure and public health, Environ. Health Perspect. 108 (2000) 123.
[2] H.M.E. Miedema, C.G.M. Oudshoorn, Annoyance from transportation noise: relationships with exposure metrics DNL and DENL and their confidence intervals, Environ. Health Perspect. 109 (2001) 409–416.
[3] P.V. Knipschild, Medical effects of aircraft noise: community cardiovascular survey, Int. Arch. Occ. Env. Hea 40 (1977) 185–190.
[4] G.W. Evans, M. Bullinger, S. Hygge, Chronic noise exposure and physiological response: a prospective study of children living under environmental stress, Psychol. Sci. 9 (1998) 75–77.
[5] Y. Aydin, M. Kaltenbach, Noise perception, heart rate and blood pressure in relation to aircraft noise in the vicinity of the Frankfurt airport, Clin. Res. Cardiol. 96 (2007) 347–358.
[6] W.Q. Gan, H.W. Davies, M. Koehoorn, M. Brauer, Association of long-term exposure to community noise and traffic-related air pollution with coronary heart disease mortality, Am. J. Epidemiol. 175 (2012) 898–906.
[7] A. Fyhri, G.M. Aasvang, Noise, sleep and poor health: modeling the relationship between road traffic noise and cardiovascular problems, Sci. Total Environ. 408 (2010) 4935–4942.
[8] W. Babisch, G. Pershagen, J. Selander, D. Houthuijs, O. Breugelmans, E. Cadum, et al., Noise annoyance — a modifier of the association between noise level and cardiovascular health? Sci. Total Environ. 452 (2013) 50–57.
[9] H. Guite, C. Clark, G. Ackrill, The impact of the physical and urban environment on mental well-being, Public Health 120 (2006) 1117–1126.
[10] C. Maschke, H. Niemann, Health effects of annoyance induced by neighbour noise, Noise Control Eng. J. 55 (2007) 348–356.
[11] V. Hongisto, M. Mäkilä, M. Suokas, Satisfaction with sound insulation in residential dwellings—the effect of wall construction, Build. Environ. 85 (2015) 309–320.
[12] S.H. Park, P.J. Lee, K.S. Yang, K.W. Kim, Relationships between non-acoustic factors and subjective reactions to floor impact noise in apartment buildings, J. Acoust. Soc. Am. 139 (2016) 1158–1167.
[13] S.H. Park, P.J. Lee, K.S. Yang, Perception and reaction to floor impact noise in apartment buildings: a qualitative approach, Acta Acust. United Ac 102 (2016) 902–911.
[14] Y. Zhao, S. Zhang, S. Selvin, R.C. Spear, A dose response relation for noise induced hypertension, Br. J. Industrial Med. 48 (1991) 179–184.
[15] V. Regecová, E. Kellerová, Effects of urban noise pollution on blood pressure and heart rate in preschool children, J. Hypertens. 13 (1995) 405–412.
[16] M. Basner, W. Babisch, A. Davis, M. Brink, C. Clark, S. Janssen, et al., Auditory and non-auditory effects of noise on health, Lancet 383 (2014) 1325–1332.
[17] B. Berglund, T. Lindvall, D.H. Schwela, Guidelines for Community Noise, World Health Organization, 1999.
[18] M.M. Bradley, P.J. Lang, Affective reactions to acoustic stimuli, Psychophysiology 37 (2000) 204–215.
[19] K. Hume, M. Ahtamad, Physiological responses to and subjective estimates of soundscape elements, Appl. Acoust. 74 (2013) 275–281.
[20] P. Gomez, B. Danuser, Affective and physiological responses to environmental noises and music, Int. J. Psychophysiol. 53 (2004) 91–103.
[21] S. Holand, A. Girard, D. Laude, C. Meyer-Bisch, J.-L. Elghozi, Effects of an auditory startle stimulus on blood pressure and heart rate in humans, J. Hypertens. 17 (1999) 1893–1897.
[22] P.J. Lee, J.H. Kim, J.Y. Jeon, Psychoacoustical characteristics of impact ball sounds on concrete floors, Acta Acust. United Ac 95 (2009) 707–717.
[23] J.Y. Jeon, P.J. Lee, S. Sato, Use of the standard rubber ball as an impact source with heavyweight concrete floors, J. Acoust. Soc. Am. 126 (2009) 167–178.
[24] J.Y. Jeon, P.J. Lee, J.H. Kim, S.Y. Yoo, Subjective evaluation of heavy-weight floor impact sounds in relation to spatial characteristics, J. Acoust. Soc. Am. 125 (2009) 2987–2994.
[25] S.H. Park, P.J. Lee, B.K. Lee, Levels and sources of neighbour noise in heavyweight residential buildings in Korea, Appl. Acoust. 120 (2017) 148–157.
[26] ISO 10140-5, Acoustics - Laboratory Measurement of Sound Insulation of Building Elements, Part 5: Requirements for Test Facilities and Equipment, International Organization for Standardization, Geneva, Switzerland, 2010.
[27] J. Little, J. Mabry, Sound duration and its effect on judged annoyance, J. Sound. Vib. 9 (1969) 247–262.
[28] P.D. Schomer, L.R. Wagner, On the contribution of noticeability of environmental sounds to noise annoyance, Noise Control Eng. J. 44 (1996) 294–305.
[29] S. Fidell, S. Teffeteller, R. Horonjeff, D.M. Green, Predicting annoyance from detectability of low-level sounds, J. Acoust. Soc. Am. 66 (1979) 1427–1434.
[30] M. Sneddon, K. Pearsons, S. Fidell, Laboratory study of the noticeability and annoyance of low signal-to-noise ratio sounds, Noise Control Eng. J. 51 (2003) 300–305.
[31] H.S. Friedman, C.E. Priebe, Estimating stimulus response latency, J. Neurosci. Methods 83 (1998) 185–194.
[32] F.K. Graham, R.K. Clifton, Heart-rate change as a component of the orienting response, Psychol. Bull. 65 (5) (1966) 305–320.
[33] M.E. Dawson, A.M. Schell, D.L. Filion, The electrodermal system, in: J.T. Cacioppo, L.G. Tassinary, G.G. Berntson (Eds.), Handbook of Psychophysiology, Cambridge University Press, USA, 2007, pp. 159–181.
[34] L. Kaiser, Adjusting for baseline: change or percentage change? Statistics Med. 8 (1989) 1183–1190.
[35] S. Abo-Qudais, H. Abu-Qdais, Perceptions and attitudes of individuals exposed to traffic noise in working places, Build. Environ. 40 (2005) 778–787.
[36] J.Y. Jeon, J.K. Ryu, J.H. Jeong, H. Tachibana, Review of the impact ball in evaluating floor impact sound, Acta Acust. United Ac 92 (2006) 777–786.
[37] P.J. Lang, M.M. Bradley, B.N. Cuthbert, Motivated attention: affect, activation, and action, in: P.J. Lang, R.F. Simons, M.T. Balaban (Eds.), Attention and Orienting: Sensory and Motivational Processes, Lawrence Erlbaum Associates, 1997, pp. 97–135.
[38] W. Boucsein, Electrodermal Activity, Springer Science & Business Media, 2012.
[39] A. Tajadura-Jiménez, P. Larsson, A. Väljamäe, D. Västfjäll, M. Kleiner, When room size matters: acoustic influences on emotional responses to sounds, Emotion 10 (2010) 416–422.
[40] T. Reinhardt, C. Schmahl, S. Wüst, M. Bohus, Salivary cortisol, heart rate, electrodermal activity and subjective stress responses to the Mannheim Multicomponent Stress Test (MMST), Psychiat Res. 198 (2012) 106–111.
[41] P. Lindborg, Physiological measures regress onto acoustic and perceptual features of soundscapes, The 3rd International Conference on Music & Emotion, ICME3, Jyväskylä, Finland, 2013.
[42] O. Medvedev, D. Shepherd, M.J. Hautus, The restorative potential of soundscapes: a physiological investigation, Appl. Acoust. 96 (2015) 20–26.
[43] P. Gomez, P. Zimmermann, S. Guttormsen-Schär, B. Danuser, Respiratory responses associated with affective processing of film stimuli, Biol. Psychol. 68 (2005) 223–235.
[44] S.A. Stansfeld, Noise, noise sensitivity and psychiatric disorder: epidemiological and psychophysiological studies, Psychol. Med. Monogr. Suppl. 22 (1992) 1–44.
[45] L.K. Zahr, J. de Traversay, Premature infant responses to noise reduction by earmuffs: effects on behavioral and physiologic measures, J. Perinatology 15 (1994) 448–455.
[46] R.F.S. Job, Community response to noise — a review of factors influencing the relationship between noise exposure and reaction, J. Acoust. Soc. Am. 83 (1988) 991–1001.
[47] E. Öhrström, M. Björkman, R. Rylander, Noise annoyance with regard to neurophysiological sensitivity, subjective noise sensitivity and personality variables, Psychol. Med. 18 (1988) 605–613.

Building and Environment 136 (2018) 302–311

Contents lists available at ScienceDirect

Building and Environment

journal homepage: www.elsevier.com/locate/buildenv

Effects of noise sensitivity on psychophysiological responses to building noise

Sang Hee Park[a], Pyoung Jik Lee[a,*], Jeong Ho Jeong[b]

[a] Acoustics Research Unit, School of Architecture, University of Liverpool, Liverpool, UK
[b] Fire Safety & Building Environment System Research Team, Fire Insurers Laboratories of Korea, South Korea

ARTICLE INFO

Keywords:
Noise sensitivity
Psychophysiological responses
Building noise
Floor impact noise

ABSTRACT

The present study aims to explore the effects of noise sensitivity on psychophysiological responses to floor impact noises and road traffic noise. A standard impact source (i.e. an impact ball) and two real impact sources (i.e. an adult's walking and a child's running) were used to record floor impact noises, while road traffic noise was introduced as an outdoor noise stimulus. A total of 34 subjects were recruited based on their self-rated noise sensitivity and classified into low and high noise sensitivity groups. During the laboratory experiments, all the noise stimuli were presented for 5 min each, and the subjects rated their annoyance with each stimulus at the end of each session. Their physiological responses (heart rate: HR, electrodermal activity: EDA, and respiratory rate: RR) were measured throughout the experiment. The obtained noise annoyance ratings increased with increasing noise levels for all the sources, and the high noise sensitivity group exhibited higher annoyance ratings than the low noise sensitivity group. All physiological measures varied significantly with the duration of noise exposure. In particular, the EDA and RR values decreased sharply after 30 s, demonstrating strong habituation over time. Noise sensitivity was found to significantly affect physiological responses, whereas noise levels showed no significant influence.

1. Introduction

It is well-known that both acoustic and non-acoustic factors contribute to noise annoyance [1–6]. In particular, noise sensitivity has been reported as a significant non-acoustic factor affecting annoyance. Several studies have concluded that subjectively reported noise sensitivity alters the effect of noise exposure on annoyance [7–9], while others have confirmed that annoyance ratings are greater for people with higher noise sensitivities [10,11]. Recent studies have also indicated that the prediction of noise annoyance can be considerably improved by adding noise sensitivity [12,13]. However, research to date has tended to focus on outdoor environmental noise (i.e. road traffic and aircraft noise), while little attention has been paid to indoor noise such as noise from neighbours.

Recent evidence has highlighted that annoyance is related to non-auditory effects of noise, such as physical and mental health problems [5,14–16]. Guski [5] suggested that a relationship exists between annoyance and negative feelings caused by noise, while Stansfeld and Matheson [14] reported that noise might have serious psychological effects. Furthermore, Maschke and Niemann [16] found that annoyance induced by neighbour noise had negative effects on both physical and mental health, such as cardiovascular health risks, migraine, or depression. More recently, a series of studies on building noise proposed the relationship between the annoyance caused by floor impact noise and health-related complaints [17,18]. So far, however, there has been little discussion on the relationship between annoyance and physiological responses. In particular, physiological measurements have been mainly used for emotional states [19–21] and physical health risks [22–25].

Physiological parameters are responsive to various emotional states including threat, frustration, anger, startle, and (un)pleasantness. Therefore, an experimental setting with various stimuli (e.g. acoustic modalities) is widely used to investigate affective responses through physiological measures [20]. Several attempts have also been made to explore physiological changes due to arousal-evoking stimuli [26]. For instance, it was found that heart rates decelerate, while electrodermal activity and respiration increase [20,27–29] after presentation of stimuli. It was also observed that subjective estimations, particularly arousal and pleasantness, were linked to physiological changes [30–33]. In addition, several studies tried to investigate the impacts of acoustic stimuli on physiological responses. Björk [34] found that electrodermal activity increased for the stimuli exceeding 70 dBA.

---

[*] Corresponding author. Acoustics Research Unit, School of Architecture, University of Liverpool, Liverpool, L69 7ZN, UK.
E-mail address: P.J.Lee@liverpool.ac.uk (P.J. Lee).

https://doi.org/10.1016/j.buildenv.2018.03.061
Received 5 December 2017; Received in revised form 29 March 2018; Accepted 31 March 2018

Stansfeld [35] claimed that most physiological responses to noise habituated rapidly and suggested that noise sensitivity was related to higher electrodermal activity and heart rate, indicating physiological arousal to noise [35]. Hume and Ahtamad [33] reported that unpleasant acoustic stimuli caused larger falls in heart rate, while more pleasant sound stimuli resulted in bigger rises in respiratory rate. However, the acoustic stimuli used in the aforementioned studies are steady-state sounds and only lasted for short time periods ranging from 4 to 30 s; thus, the impacts of acoustic stimuli on physiological responses are still questionable for realistic situations with longer durations of noise exposure.

Stansfeld [35] provided an extensive review on relationships between noise sensitivity and various responses to environmental noise. It was suggested that, for noise sensitive individuals, greater awareness of external events contributes to the physiological responses or vice versa [35]. In particular, it was reported that high noise sensitivity is associated with higher level of physiological arousal, phobic, and defence/startle responses, as well as slower habituation to noise [35]. These mechanism between noise sensitivity and physiological responses has been empirically validated by studies on environmental noise [8,11,35,36]. Bigger changes in heart rates [8,35], higher skin conductance levels, and slower habituation [11,35] were observed from noise sensitive subjects while they were exposed to high noise levels. In addition, Heinonen-Guzejev et al. [36] found a significant increase in cardiovascular mortality from noise sensitive subjects. On the other hand, there is a lack of evidence explaining the link between noise sensitivity and physiological response in the research field on building noise. It has been found that noise sensitive individuals reported higher annoyance to various kinds of indoor noise [37] including floor impact noise [17,18]. Furthermore, noise sensitivity has been reported to increase health complaints either directly or indirectly [17,18]. While the association noise sensitivity and physiological responses to building noise was not explored in detail, it is worth examining the response evoked by building noise and compare the responses between different noise sensitivities.

The main purpose of this study is to develop an understanding of how noise sensitivity might affect perception of noise and physiological responses to noise. It was hypothesised that psychophysiological responses to noise might be different across subjective noise sensitivity and types of noise sources. Therefore, the subjects were recruited based on their self-rated noise sensitivity and classified into low and high noise sensitivity groups. Transient building noise transmitted from the neighbours was used as a major type of noise stimuli, and steady-state noise (road traffic noise) was added for comparison. Laboratory experiments were conducted by using 5 min long noise stimuli. Noise annoyance was evaluated after each stimulus presentation, and three physiological measures (heart rate, electrodermal activity, and respiratory rate) were monitored throughout the experiment.

2. Methods

2.1. Subjects

A simple online survey was conducted in order to examine subjects' experience and attitude to floor impact noise. A link of the survey was emailed to people who showed their interest in participating in the experiment. They were asked to answer several questions about their demographic characteristics, residential situation, previous experience of being exposed to floor impact noise, noise sensitivity, and attitude to the noise source. For the attitude to the source, six questions about the upstairs neighbours [18] including 'I am happy with living downstairs of my upstairs neighbours' were asked, and the replies were rated on a 5-point scale. Noise sensitivity was evaluated using the 21 questions developed by Weinstein [38].

This study aimed to recruit more than 26 participants since this number of participants are required to obtain 0.8 of statistical power in correlation analysis. A total of 34 Korean subjects were chosen based on their responses. They included 13 males and 21 females aged between 30 and 48 (mean = 38.8, std. deviation = 5.3). Half of them were in their 30s, and the other half in their 40s. The median noise sensitivity score of the subjects (median = 81.5) was computed and used to split the subjects into one group exhibiting 'low noise sensitivity' (median = 61 and std. deviation = 6.6) and another exhibiting 'high noise sensitivity' scores (median = 99 and std. deviation = 5.9). As listed in Table 1, either group contained 17 subjects. Thirteen subjects were either not married or married but had no children, and others reported that they had one or more children. It was found that 14 subjects showed positive attitude to their upstairs neighbours, whereas negative attitude was found for 20 subjects. Attitude score difference between the low and high noise sensitivity groups was not significant. The mean duration of residency in their current accommodation was three years; thus the subjects were also divided into two groups based on whether they lived in their current residence for less or more than three years. Eighteen subjects had lived in their current residence for less than three years, while the rest had lived in their residences for more than three years. It was found that 12 subjects had experience of making noise complaints regarding the noise from their upstairs neighbours.

Table 1
Demographic and attitudinal factors for the subjects (N = 34).

		Number	%
Gender	Male	13	38.2
	Female	21	61.8
Age	30s	17	50.0
	40s	17	50.0
Noise sensitivity	Low	17	50.0
	High	17	50.0
Child(ren) at home	Yes	21	61.8
	No	13	38.2
Attitude to upstairs neighbours	Positive	14	41.2
	Negative	20	58.8
Length of residency	Less than 3 years	18	52.9
	More than 3 years	16	47.1
Experience of making noise complaints	Yes	12	35.3
	No	22	64.7

2.2. Stimuli

In the present study, both transient and steady-state noises were used as noise stimuli. Floor impact noise, which represented the transient noise, consisted of real and standard impact noises induced by human footsteps (hereinafter 'real' or 'R') and a standard heavy-weight impact source (impact ball, hereinafter 'ball' or 'B'). Road traffic noise (hereinafter 'traffic' or 'T') representing the steady-state noise was introduced for comparison with transient noises. Floor impact noises were recorded in a test building with a low background noise level (~25 dBA). The floor layer of the test building consisted of a 210 mm thick concrete slab, 30 mm thick resilient material, 40 mm thick lightweight concrete, and 40 mm thick mortar. The room where the recording was carried out was furnished with wooden flooring. An adult walking barefoot (70 kg) and a child running barefoot (24 kg) were chosen as the dominant real sources in residential buildings [39], while an impact ball [40] dropped from 1 m height was used as standard impact noise. All the floor impact noises were recorded binaurally using a head and torso simulator (Brüel & Kjær Type 4128C) positioned on a sofa in the receiving room downstairs. The road traffic noise was recorded near a motorway in the suburb of Liverpool. A microphone (Behringer ECM8000) connected to a digital recorder (ZOOM H4n) was positioned 2 m away from the motorway and 1.5 m above the ground. The motorway width was 11 m (35 feet), and the average vehicle speed was ~60 km/h (37 mph). The traffic flow was fluctuating due to a

Table 2

Noise levels of stimuli (dBA): A-weighted maximum sound pressure level (L_{AFmax}), A-weighted equivalent sound pressure level ($L_{Aeq,5min}$), A-weighted sound exposure level (L_{AE}), and percentile sound pressure levels (L_{10} and L_{90}).

Stimuli source	Label	L_{AFmax}	$L_{Aeq,5\ min}$	L_{AE}	L_{10}	L_{90}
Ball	B40	40.0	29.3	54.1	32.5	24.4
	B50	50.0	37.8	62.6	41.8	25.2
	B60	60.0	47.6	72.4	51.8	29.4
Real	R40	40.0	30.1	54.9	34.0	25.5
	R50	50.0	38.9	63.7	43.6	30.7
	R60	60.0	48.9	73.7	53.6	40.8
Traffic	T40	48.8	40.0	64.8	44.1	28.5
	T60	68.8	60.0	84.8	64.1	48.5

roundabout located around 160 m (0.1 miles) away.

Using the recordings, all the noise stimuli were edited to have the duration of 5 min. For the floor impact noise, only signals in the right channel were extracted from the binaural recordings in order to avoid any possible effects of spatial characteristics on perception [41]. The ball noises recorded at regular intervals between the impacts were edited to replicate the footstep noise. For the road traffic noise, spectral filtering was applied to simulate the outdoor-to-indoor noise attenuation using the condition of a closed window. Of different simulated closed windows [42], an attenuation with a median degree of isolation was adopted in this study similarly to a previous study [43]. In this condition, the attenuation increased from 12 dB for the 16 Hz and 31.5 Hz octave bands up to 35 dB for the 8 kHz octave band [42,43]. Temporal features of the noise stimuli are listed in Table 2 in terms of A-weighted equivalent sound pressure levels (L_{Aeq}), A-weighted maximum sound pressure levels (L_{AFmax}), A-weighted sound exposure levels (L_{AE}), and the level exceeded for 10% of the measurement period (L_{10}). Fig. 1 shows the frequency characteristics of the two floor impact noises at 60 dBA (L_{AFmax}) and the road traffic noise at 60 dBA ($L_{Aeq,5\ min}$). Compared to the road traffic noise, the two floor impact noises show their dominant sound pressure levels at low frequencies below 125 Hz.

2.3. Experimental design

In the present study, all the noise stimuli lasted for 5 min to understand the variations of the physiological responses over time. It was also hypothesised that the noise level and type of impact source might affect the responses. The sound pressure levels of the floor impact noises (L_{AFmax}) were fixed at 40, 50, and 60 dBA because the floor impact noise was rarely noticed at levels below 40 dBA [17]. For comparison with the outdoor noise, the road traffic noises were set at 40 and 60 dBA (L_{Aeq}).

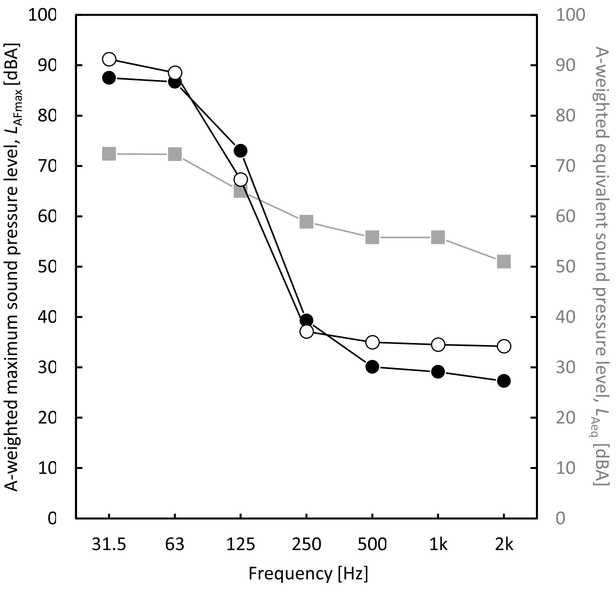


Fig. 1. Frequency characteristics of the noise stimuli. Black lines represent L_{AFmax} and grey line represents L_{Aeq}. ●: impact ball, ○: real impact source, and ■: road traffic.

Each subject took part in eight sessions with different noise levels and sources. The duration of each session was around 8 min including a rest period (i.e. baseline, 2 min), noise exposure (5 min), and evaluation of the noise annoyance (30s). All sessions were spaced at equal intervals of 2 min silent baselines and presented randomly in order to avoid any possible order effect [44].

The sounds above 63 Hz were reproduced using a loudspeaker (Genelec 8050 A), while the low-frequency sounds below 63 Hz were presented using a subwoofer (Velodyne MicroVee) placed in front of the subjects. A low-pass filter with a cut-off frequency of 63 Hz in the octave band was applied to the sounds reproduced by the subwoofer. An additional loudspeaker was used for producing ambient noise at 31 dBA.

2.4. Psychophysiological measurements

After the noise exposure for 5 min, the subjects were asked to rate their annoyance using an 11-point scale (0 = '*Not at all*' to 10 = '*Extremely*') at the end of each session. Three physiological responses were measured for the entire duration of each session: heart rate (hereinafter HR), electrodermal activity (hereinafter EDA), and respiratory rate (hereinafter RR). All physiological responses were recorded via a data acquisition system (BIOPAC Systems MP150) and analysed using AcqKnowledge 4.4 (BIOPAC Systems). Two wireless amplifiers were placed just outside the audiometric booth where the subject was seated in. The amplifiers received all the measurement data via Bluetooth transmitting mode. The HR was derived from raw electrocardiograph data which were measured using three electrodes attached to the subject's right wrist and both ankles. The EDA was measured using two electrodes attached to the subject's index and middle fingers of the right hand. The RR was computed from raw respiration data which were measured through a respiration transducer belt worn around the subject's chest.

2.5. Procedure

The subjects were asked to avoid staying up late and drinking alcohol the night before the experiment and to avoid drinking any caffeinated drinks on the day of the experiment. The experiment was carried out in an audiometric booth where the background noise level was approximately 25 dBA. All the electrodes were attached to the subject's body once the subject finished reading the information sheet regarding the experiment and gave their consent to participate. The subject was then helped to be seated comfortably on a chair. Road traffic noise was played over a loudspeaker positioned 2 m in front of the subject, while floor impact noise was played over another loudspeaker positioned above the subject. Each subject took part in a test session at the beginning which lasted from three to 5 min in order to get all the measurement systems checked and calibrated before the experimental sessions. The room temperature and humidity were kept constant throughout the experiment to avoid their effects on the physiological responses [29].

2.6. Data analysis

Any erroneous data were discarded before the analysis [33,44], and the identified respiratory irregularities were used for judging and removing the remnant artifacts in the EDA and HR [45]. Due to the variations of the subjects' physiological responses, percentage changes

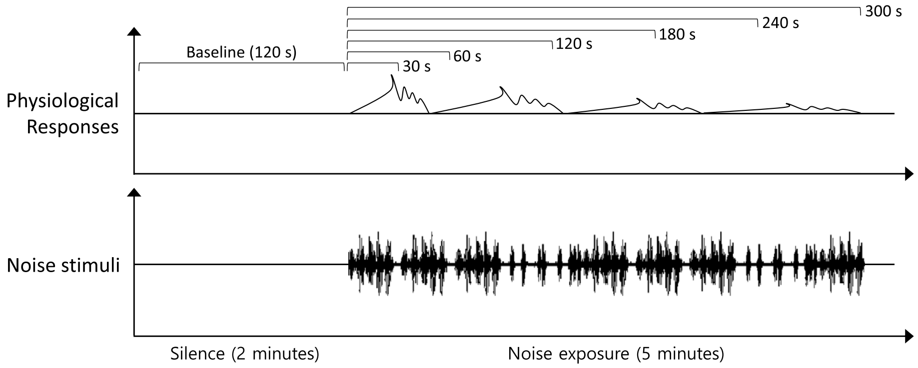


Fig. 2. Calculations of physiological responses for different durations of noise exposure (30 s, 1 min, 2 min, 3 min, 4 min, and 5 min).

(%) representing the physiological response changes from the baseline to noise exposure were calculated [46]. All the psychophysiological responses were additionally analysed to find out whether they were influenced by acoustic or non-acoustic factors. Thus, the effects of different noise levels, noise sources, noise sensitivities, and the duration of noise exposure on the psychophysiological responses were investigated. In particular, six time blocks of physiological data were analysed in order to examine whether the physiological responses varied over the 5 min intervals. Fig. 2 shows a simple illustration how all the physiological responses were computed for 30 s, 1 min, 2 min, 3 min, 4 min, and 5 min from the beginning of the noise exposure. Mean percentage changes for these six durations were calculated and compared with the mean percentage changes for the baseline before each noise exposure. As potential factors affecting the responses, several demographic factors were also considered: age, gender, duration of residency, and number of children living in the current residence. Impacts on the responses of the attitude to the noise source (upstairs neighbours) and past experience of making noise complaints were also examined.

Statistical analyses were performed using SPSS for Windows (version 22.0, SPSS Inc., Chicago, IL). Main effects of noise levels, type of sources, and duration of exposure on annoyance and physiological responses were assessed using a repeated measures analysis of variance (ANOVA). Wilcoxon signed ranks test was used to compare two related samples such as annoyance ratings of Ball and Real, while Mann-Whitney *U* test was used to test all responses between groups (e.g. noise sensitivity). In addition, an independent samples *t*-test was used to compare independent groups (e.g. the low and high noise sensitivity groups). In the present study, *p* values of less than 5% ($p < 0.05$) were considered as statistically significant.

3. Results

3.1. Noise annoyance

Fig. 3 shows the mean annoyance ratings for different noise stimuli as functions of L_{AFmax} and L_{AE}. It was found that the noise annoyance ratings increased with increasing noise level for all noise sources. The results of the repeated measures ANOVA confirm that the effect of the noise level on annoyance was significant [$F(1, 40) = 77.20, p < 0.01$]. The correlation coefficients between the annoyance ratings and noise level were 0.78 and 0.75 for the ball and the real, respectively ($p < 0.01$ for all). It was observed that the main effect of the impact noise type (ball or real) on annoyance is also significant [$F(1, 33) = 20.18, p < 0.01$]. It was found that the annoyance ratings for the real were significantly higher than the ratings for the ball at 40 and 60 dBA, which will be denoted as B40 and B60 in the following for the sake of convenience. This might be because the L_{AE} levels are quite different even at the same L_{AFmax} levels. For example, the difference in L_{AE} between the noises was 1.3 dB at L_{AFmax} = 60 dBA. The annoyance rating for the T40 case was close to those for B50 and R50 because the corresponding noise levels are similar in terms of L_{AFmax} and L_{AE}. It was also found that the annoyance rating for T60 was significantly greater than those for other stimuli.

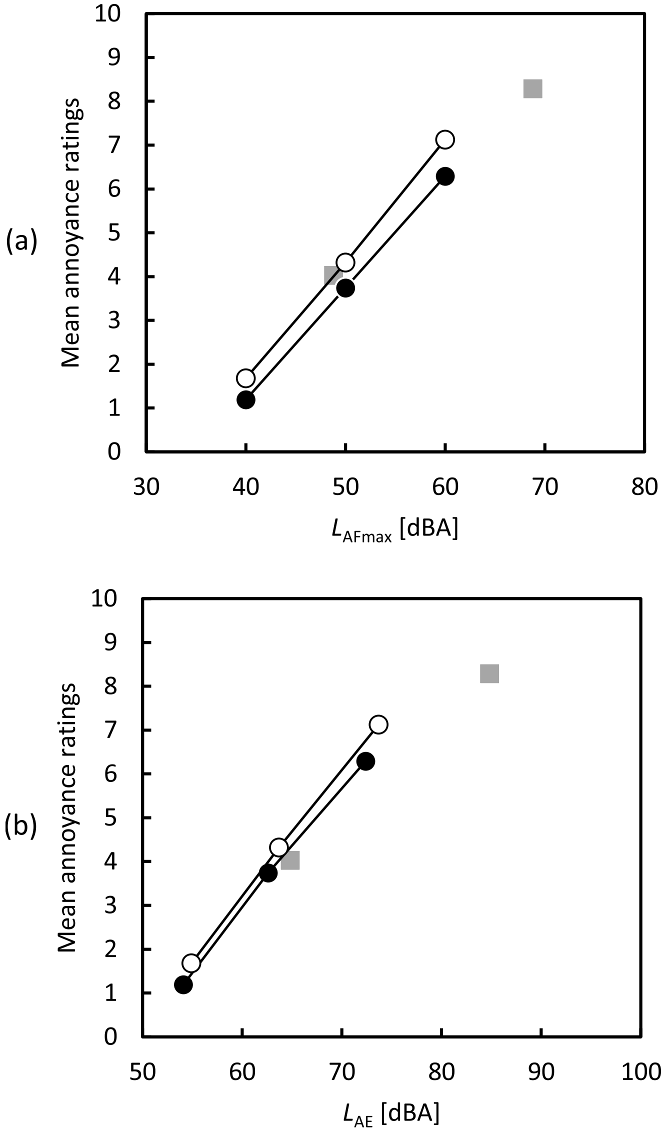


Fig. 3. Mean annoyance ratings as functions of (a) L_{AFmax} and (b) L_{AE}. ●: impact ball, ○: real impact source, and ■: road traffic.

In order to investigate the effect of noise sensitivity on noise annoyance, the noise annoyance ratings from the groups with low and

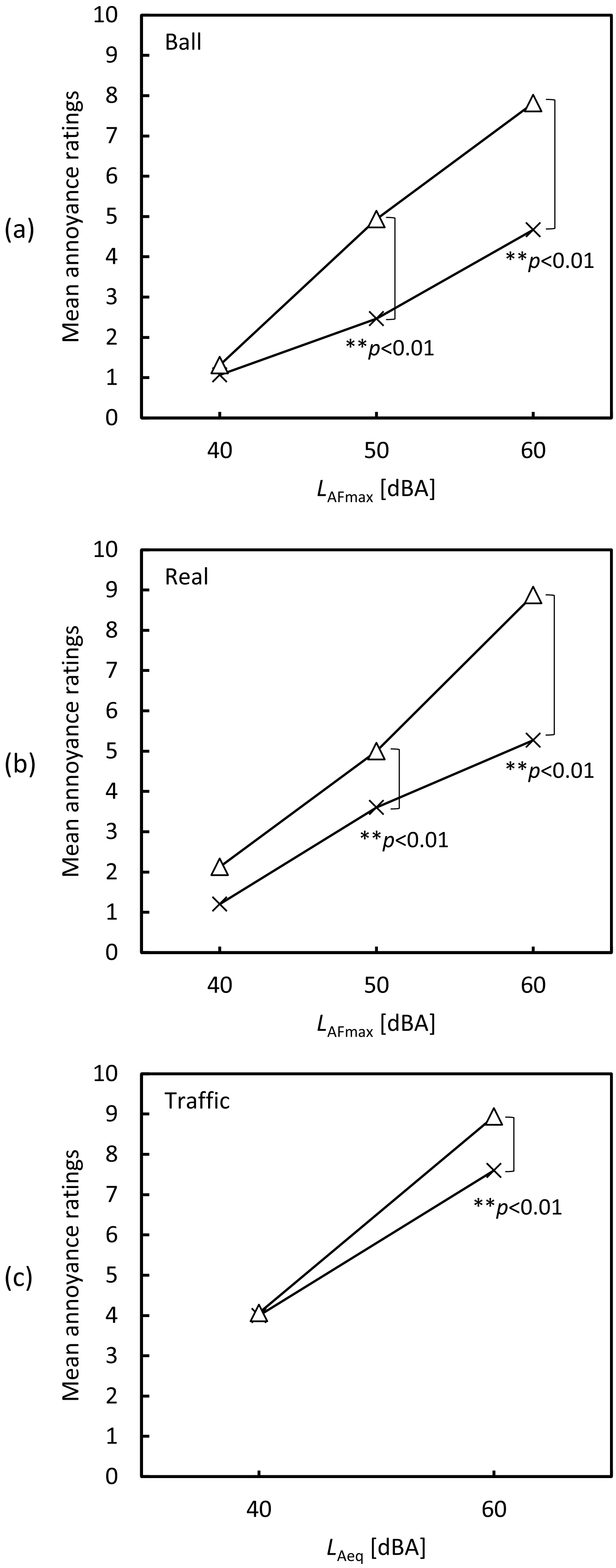


Fig. 4. Mean annoyance ratings for the low and high noise sensitivity groups: (a) impact ball, (b) real impact source, and (c) road traffic. Asterisk indicates significant differences between the low and high noise sensitivity groups ($p < 0.01$). ×: low noise sensitivity group and △: high noise sensitivity group.

high noise sensitivity scores were compared. As shown in Fig. 4(a) and Fig. 4(b), for the floor impact noise, the high noise sensitivity group reported greater annoyance ratings than the low noise sensitivity group. The differences between the two groups increased with increasing noise levels, and significant differences were found at 50 and 60 dBA. A similar tendency was found for the road traffic noise, with a significant difference between the groups at 60 dBA. For the low noise sensitivity group, the noise level showed a significant impact on annoyance [$F(1, 21) = 19.40$, $p < 0.01$], while the impact noise type (ball or real) also had a main effect on annoyance [$F(1, 16) = 11.51$, $p < 0.01$]. The correlations between the annoyance ratings and noise level were statistically significant ($r = 0.73$, $p < 0.01$ for the ball and $r = 0.71$, $p < 0.01$ for the real). Similarly, for the high noise sensitivity group, the main effect of the noise level on annoyance [$F(1, 22) = 165.31$, $p < 0.01$] and the influence of the impact noise type on annoyance [$F(1, 16) = 8.34$, $p < 0.05$] were statistically significant. The relationships between the annoyance ratings and noise level were also significant, and the correlation coefficients were greater than those for the low noise sensitivity group ($r = 0.93$, $p < 0.01$ for the ball and $r = 0.88$, $p < 0.01$ for the real). Result of Fisher's exact test confirmed that the correlation coefficients of the low and high noise sensitivity groups were significantly different ($p < 0.01$).

3.2. Physiological responses

In order to investigate how the physiological responses changed over time, the mean changes of the HR, EDA, and RR were calculated for different durations of noise exposure ranging from 30 s to 5 min. As shown in Fig. 5, the mean changes of the HR slightly increased for longer durations for both low and high noise sensitivity groups. Compared to the HR, the EDA and RR showed more pronounced dependencies on the noise exposure duration, initially increasing and then rapidly decreasing as the duration increased. For instance, for the road traffic noise, the low noise sensitivity group showed large variation of the mean change of EDA from around 2% to −5%. As listed in Table 3, the results of the repeated ANOVA confirm that the mean changes of the HR, EDA, and RR were significantly affected by the duration of noise exposure ($p < 0.01$ for all the measures and sources). Fig. 5 compares the differences between the two noise sensitivity groups. Both groups showed similar tendencies over time; however, the changes of the high noise sensitivity group were greater than those of the low noise sensitivity group. In particular, the RR showed a significant difference between the groups for all the noise sources. For the low noise sensitivity group, the mean changes of the RR recovered and showed negative values after 5 min, whereas those of the high noise sensitivity group still remained positive, implying that 5 min might not be sufficient for sensitive people to fully recover.

It is of note that the decrease of the mean changes of the EDR and RR was most significant between 30 and 60 s. This implies that the initial changes of the physiological responses (e.g. the HR deceleration, EDA increase, and RR acceleration observed for 30 s) represent arousal status [26], and the physiological responses start to recover after 30 s. Previously, Park and Lee [47] also found that arousal was caused by 23 s long stimuli of floor impact noise. Therefore, in the present study, only the mean changes for 30 s were used for the detailed analysis.

The changes in the HR, EDA, and RR for 30 s were averaged across the noise sources and are plotted in Fig. 6. The mean changes are also listed in Table 4 together with standard deviations. The HR decreased after the noise exposure, whereas the EDA and RR increased for both low and high noise sensitivity groups. The differences between the baseline and the noise exposure were statistically significant for all the noise sources and all the physiological measures ($p < 0.01$ for all). For the impact ball, the HR of the low noise sensitivity group decreased to −1%, whereas that of the high noise sensitivity group dropped to around −3% on average. Similarly, after the presentation of real impact sources and road traffic noise, the high noise sensitivity group

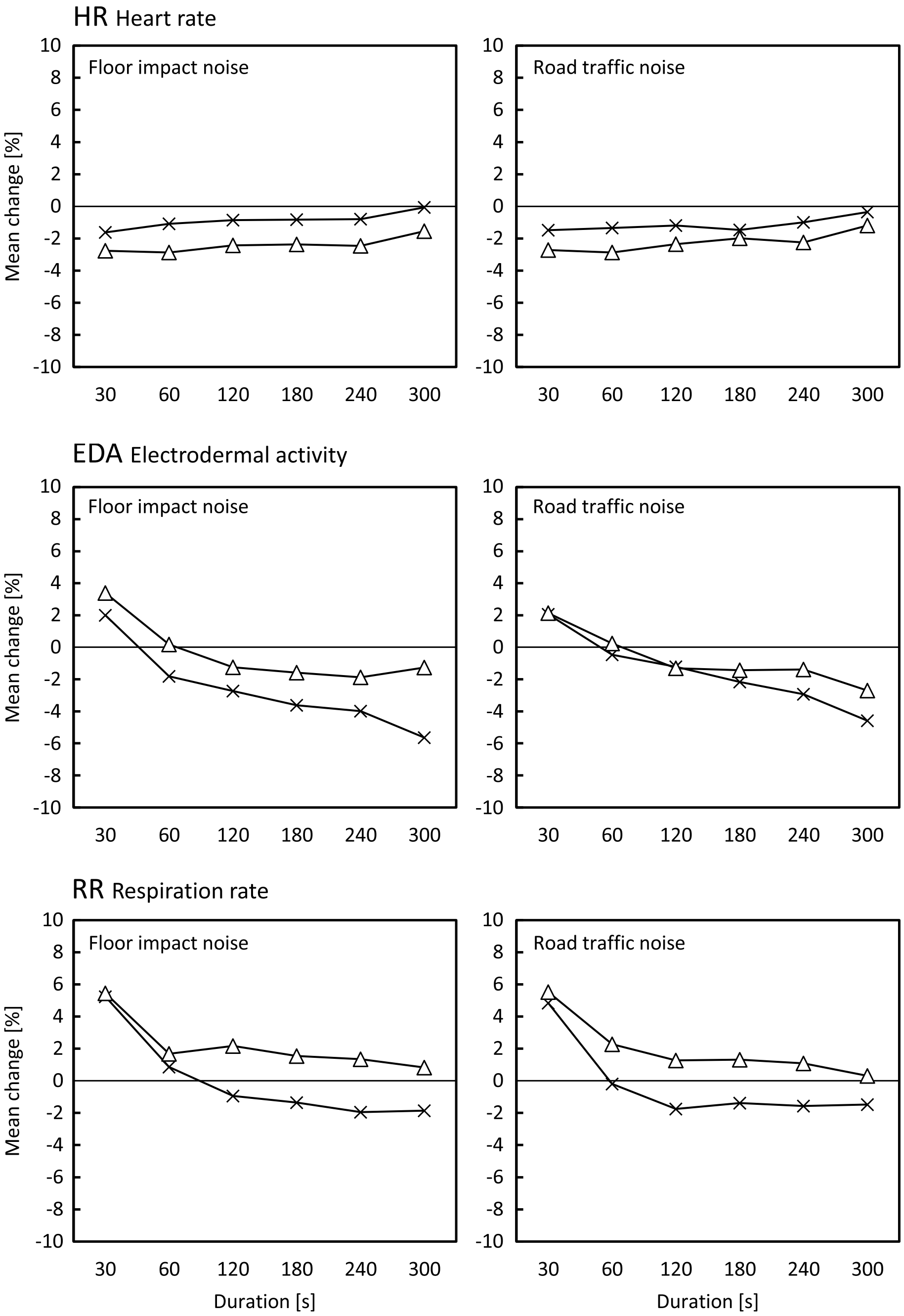


Fig. 5. Mean changes of physiological responses over different durations of noise exposure for the low and high noise sensitivity groups. ×: low noise sensitivity group and △: high noise sensitivity group.

Table 3
Results of the repeated measures analysis of variance (ANOVA) showing the effect of the varying duration of noise exposure on the HR, EDA, and RR (*$p < 0.01$).

		Impact ball		Real impact source		Road traffic	
		df	F	df	F	df	F
HR	Duration	4	9.43*	4	17.49*	4	12.26*
(Heart rate)	error	130		127		126	
EDA	Duration	2	26.91*	2	20.74*	3	22.08*
(Electrodermal activity)	error	80		61		99	
RR	Duration	3	29.06*	3	26.49*	3	22.46*
(Respiration rate)	error	99		93		91	

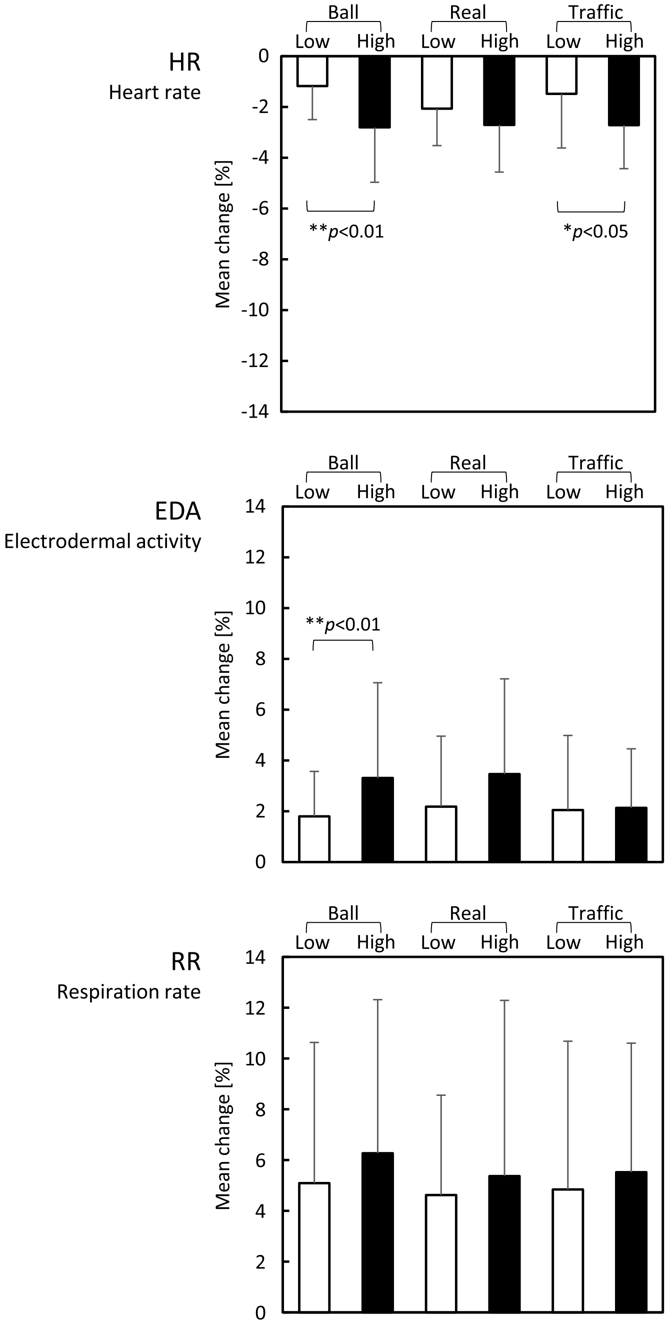


Fig. 6. Mean changes of physiological responses for the low and high noise sensitivity groups with error bars indicating standard deviations. Single and double asterisk indicates significant differences between the low and high noise sensitivity groups.

showed greater changes in the HR than the low noise sensitivity group. The independent samples *t*-test confirmed that the differences in the HR between the two groups were significant for the impact ball and road traffic noise ($p < 0.01$ for both). For the EDA, the high noise sensitivity group showed greater changes than the low noise sensitivity group for all the sources, although the difference between the groups was significant only for the impact ball ($p < 0.01$). The impact ball raised the EDA of the low noise sensitivity group by 1.80%, while the mean change of the high noise sensitivity group was more than 3% on average. For the RR, the mean changes of the high noise sensitivity group were slightly greater than those of the low noise sensitivity group; however, the differences between the groups were not significant.

The mean changes of the HR, EDA, and RR for different noise levels are plotted in Fig. 7 for the two noise sensitivity groups. The results of the repeated measures ANOVA confirmed that none of the physiological responses were significantly influenced by different noise levels and different impact sources. The decrease in the HR of the high noise sensitivity group was greater than that of the low noise sensitivity group at all levels and for all noise sources; however, there seemed to be no significant relationship between the HR changes and noise levels. The statistical significance of the differences between the two noise sensitivity groups was found at B50, B60, and R50. It was observed that the high noise sensitivity group showed greater EDA than the low noise sensitivity group at all noise levels and for both impact noise sources. However, there was no significant difference in the EDA between the two noise sensitivity groups. The RR showed no clear tendency with increasing noise level, and a significant difference between the two noise sensitivity groups was found only at B40.

4. Discussion

4.1. Impacts of noise sensitivity on annoyance and physiological responses

The majority of previous studies have mainly focused on the effects of noise sensitivity on annoyance ratings for outdoor noises such as environmental noise [3,8–11]. In contrast, the present study examined indoor building noise (i.e. floor impact noise), as well as outdoor noise (i.e. road traffic noise). The findings from the laboratory experiment revealed that high noise sensitivity significantly increased noise annoyance ratings of the indoor and outdoor noises. These results are consistent with the findings of previous studies [4,7,8,10,11,17,48,49], where noise sensitivity was found to be a crucial factor affecting annoyance for the case of environmental noises. Furthermore, the findings of this study confirm that noise sensitivity influences annoyance for indoor noise by extending an earlier study [37] on the impacts of noise sensitivity on annoyance ratings for airborne and bathroom drainage noises.

Confirming findings in a recent laboratory experiment [47], this study found decelerations in HR, increases in EDA, and accelerations in RR at the beginning of the noise exposure. Decelerating HR and increasing EDA indicate that the subjects were in 'freezing' stage accompanying with focused attention and potentiated startle [26]. In

Table 4
Mean and standard deviation values of the HR, EDA, and RR for different noise sources and noise sensitivity groups.

	Noise sensitivity group	Impact ball		Real impact source		Road traffic	
		Mean [%]	Std. Deviation	Mean [%]	Std. Deviation	Mean [%]	Std. Deviation
HR	Low	−1.18	0.01	−2.07	0.01	−1.48	0.02
(Heart rate)	High	−2.81	0.02	−2.71	0.02	−2.72	0.02
EDA	Low	1.80	0.02	2.19	0.03	2.05	0.03
(Electrodermal activity)	High	3.31	0.04	3.46	0.04	2.14	0.02
RR	Low	5.09	0.06	4.62	0.04	4.84	0.06
(Respiration rate)	High	6.27	0.06	5.37	0.07	5.52	0.05

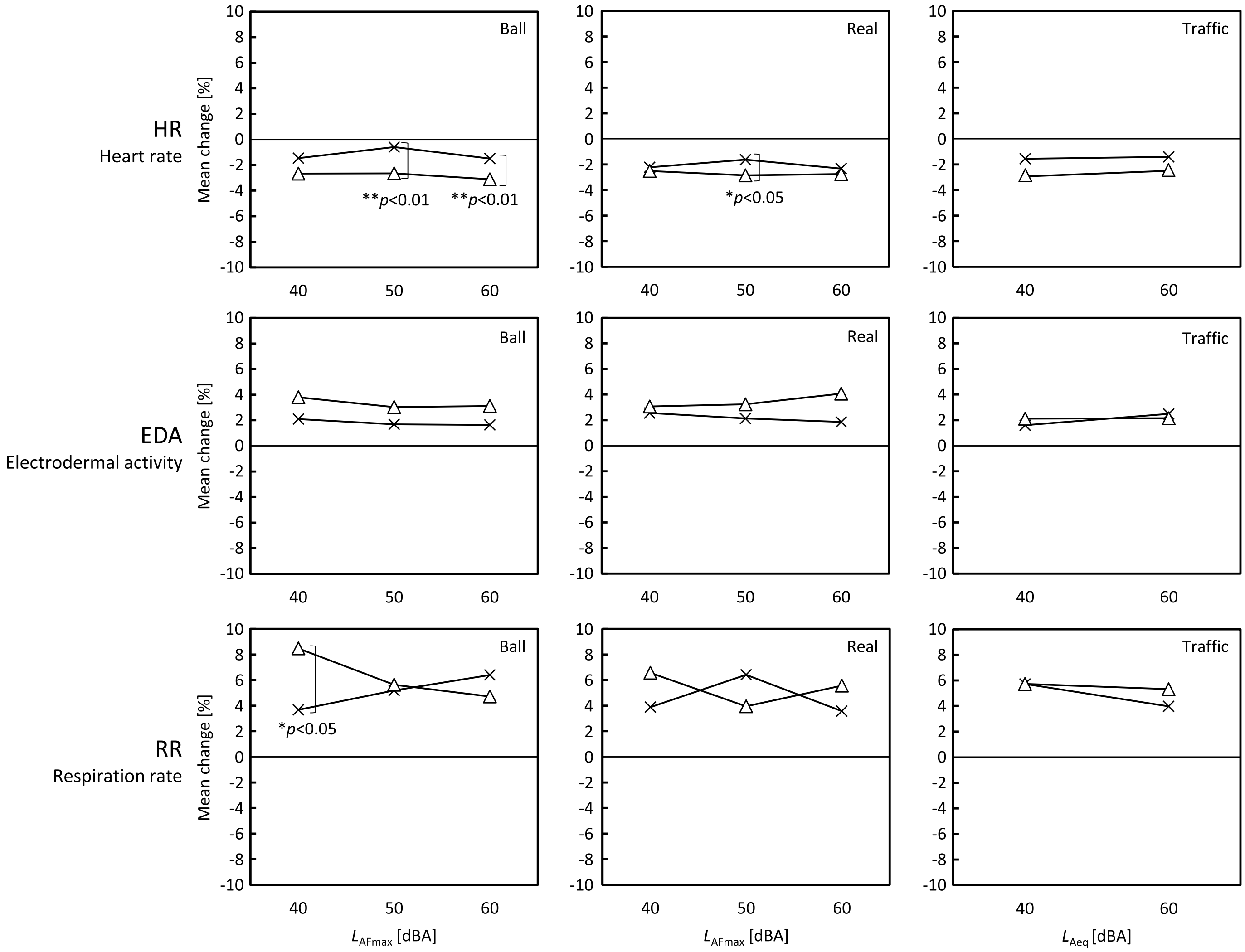


Fig. 7. Mean changes of physiological responses along with noise levels for the low and high noise sensitivity groups. Single and double asterisks indicate significant differences between the low and high noise sensitivity groups. ×: low noise sensitivity group and △: high noise sensitivity group.

other words, the exposure to the noise stimuli evoked ‘freezing’ responses from the participants. In contrast, HR accelerates and EDA keeps increasing in the ‘circa-strike’ stage where individuals take either ‘fight or flight’ response [26]. This study also showed that physiological responses to noise were significantly different for varying noise sensitivity. In particular, the changes in physiological responses from noise sensitive group were greater than those from the low noise sensitivity group. Greater deceleration in HR and greater increases in EDA and RR were found from the subjects with high noise sensitivity for all the noise sources, durations, and most of the noise levels. These results imply that the subjects with higher noise sensitivity had the greater 'freezing' responses because they paid more attention to the stimuli compared with subjects with low noise sensitivity.

In previous studies, noise-sensitive subjects showed higher EDA and HR [35] and cardiovascular mortality significantly increased among noise-sensitive women [36]. This study also found different physiological responses between low and high noise sensitivity groups. However, the findings of this study showed a partial disagreement with Stansfeld [35] because, in the present study, noise sensitive subjects consistently showed lower HR compared to subjects with low noise sensitivity. This disagreement can be explained by different noise levels at which the noise stimuli were presented. In the present study, noise levels varied between 40 and 60 dBA, whereas Stansfeld [35] presented the stimuli in the region between 75 and 100 dBA. This implies that noise sensitive subjects in this study paid more attention to the stimuli than low noise sensitivity group in the ‘freezing’ stage [26], whereas noise sensitive subjects in the previous study [35] were in the ‘circa-strike’ stage due to greater noise levels, representing bigger ‘alarmed’ response than low noise sensitivity group.

4.2. Other factors affecting noise annoyance and physiological responses

The findings of the present study are in agreement with previous studies [50–52] reporting that noise annoyance is significantly affected by sound pressure levels. In particular, this result is in good agreement with the work of Park and Lee [47], where the annoyance caused by floor impact noise increased with the noise level. Contrary to the noise annoyance, physiological responses were not affected by the noise levels for different noise sources. However, Park and Lee [47] recently reported that the EDA and RR changes were correlated with sound pressure levels for floor impact noises. The disagreement may be attributed to the different settings of the laboratory experiments. Park and Lee [47] employed a wider range of sound pressure levels (from 31.5 to 63 dBA, L_{AFmax}) than the current study; thus it was possible to investigate the relationship between the noise levels and physiological responses. In comparison, in the present study we carried out tests only for three sound pressure levels with longer noise exposure and focused on the effect of noise sensitivity, so the limited data did not allow us to confirm the impact of the noise levels on the physiological responses.

Park and Lee [47] previously reported that annoyance ratings and physiological responses showed significant differences for different types of impact sources (ball or real). However, the present study did not find such differences in the physiological measures, which might be due to the differences in the time histories of the impact ball noises used here. In the previous study [47], the impact ball noises consisted of ten single impulsive noises at regular intervals and showed significantly different waveforms compared to the real noises. In contrast, the present study edited the impact ball noises to replicate the waveforms of the real impact noises. This result implies that human hearing and perception (i.e. subjective annoyance rating) are more sensitive than physiological responses to the differences between the impact ball and real impact noises.

In the present study, it was found that none of the demographic factors such as age and gender affected the annoyance ratings and physiological responses. Several studies [48,49,53] have reported that attitudinal factors affected noise annoyance; however, this was not the case in the present study. This indicates that the questions used in this study to measure the attitude of the subjects to the noise source might have not been chosen in the best way. In contrast to the environmental noise studies [49,53,54], where the noise sources are clear and simple, it is much more complicated to identify the sources in apartment buildings. Therefore, in the present study, the attitude to the noise from the upstairs neighbours was assessed assuming that this type of noise sources would be dominant. Nevertheless, the findings of this study suggest that direct questions about the subject's attitude to noise or their emotions expressed under noise exposure might be useful in the future.

4.3. Effects of noise exposure duration on annoyance and physiological responses

The laboratory experiment showed significant effects of noise exposure duration on all the physiological responses, with the HR accelerating and EDA and RR decreasing for longer durations. The acceleration of the HR can be interpreted by the subjects experiencing stronger arousal based on the model stating the relationship between physiological responses and arousal intensity [26]. According to the model proposed by Lang et al. [26], the HR accelerates with increasing arousal intensity. However, an increase in the HR can also be seen even as the habituation to the stimuli or recovery phase occur after a certain degree of deceleration [55]. Habituation is defined as a decrease in the strength of the response after repeated presentation of the same stimulus [56]. During the laboratory experiments, the noises induced by footsteps and vehicles were repeated for 5 min; thus, the responses evoked by the same stimulus could decrease. Similar tendencies were found in the EDA and RR changes, indicating strong habituation over time [55,57]. The EDA and RR increased by the initial stimulus presentations and then sharply decreased after 30 s. Most changes in the EDA and RR over time stabilised in the region between 1 min and 5 min. These results clearly indicate that the subjects experienced arousal in the very beginning due to the noise stimuli, but their responses started to habituate after a certain period of time. Previous studies [58,59] have also reported that the initial arousal responses changed and recovered over time. Brosschot and Thayer [58] measured the HR together with the emotional arousal eight times for each participant, at 1-h intervals. They reported that negative emotions delayed HR recovery compared to positive emotions [58]. In addition, Gerin et al. [59] carried out HR and blood pressure measurements simultaneously with performing anger-recall tasks. They found longer blood pressure recovery time from participants who tended to ruminate about their past events which provoked anger [59]. As both previous studies [58,59] suggested, it can be assumed that emotional responses have meaningful impacts on physiological responses. Future research on emotional responses evoked by floor impact noise would be of worth assessing in order to understand broader responses to this noise issue.

5. Conclusion

The present study investigated psychophysiological responses (annoyance, HR, EDA, and RR) to floor impact noises and road traffic noise for the low and high noise sensitivity subject groups. It was found that the annoyance ratings increased with increasing sound pressure levels (40, 50, and 60 dBA for the floor impact noises (L_{AFmax}) and 40 and 60 dBA for the road traffic noise (L_{Aeq})). The high noise sensitivity group showed significantly greater annoyance ratings than the low noise sensitivity group for all the sources. The physiological responses to noise stimuli were calculated for different durations of noise exposure from 30 s to 5 min. The EDA and RR initially increased and then rapidly decreased after 30 s, indicating strong habituation over time. Deceleration of the HR and increase of the EDA and RR were found during 30 s noise exposure; the high noise sensitivity group showed more pronounced changes in the physiological responses than the low noise sensitivity group. The physiological responses were not affected by the type of noise source (standard or real impact source) and the sound pressure level. Age, gender, and attitude to the noise source did not affect the annoyance ratings and physiological responses. The findings of this study could contribute to the development of guideline and policy on building noise by considering the residents' subjective noise sensitivity. Further study is needed to confirm the variations in the physiological responses due to noise exposure in real situations.

Acknowledgement

This research was supported by a grant (18RERP-B082204-05) from Residential Environment Research Program funded by Ministry of Land, Infrastructure and Transport of Korean Government.

References

[1] J.M. Fields, J.G. Walker, Comparing the relationships between noise-level and annoyance in different surveys - a railway noise vs. aircraft and road traffic comparison, J. Sound Vib. 81 (1) (1982) 51–80.
[2] H.M.E. Miedema, C.G.M. Oudshoorn, Annoyance from transportation noise: relationships with exposure metrics DNL and DENL and their confidence intervals, Environ. Health Perspect. 109 (4) (2001) 409–416.
[3] M.E. Nilsson, A-weighted sound pressure level as an indicator of short-term loudness or annoyance of road-traffic sound, J. Sound Vib. 302 (1) (2007) 197–207.
[4] J.M. Fields, Effect of personal and situational variables on noise annoyance in residential areas, J. Acoust. Soc. Am. 93 (5) (1993) 2753–2763.
[5] R. Guski, Personal and social variables as co-determinants of noise annoyance, Noise Health 1 (3) (1999) 45–56.
[6] H.E. Laszlo, E.S. McRobie, S.A. Stansfeld, A.L. Hansell, Annoyance and other reaction measures to changes in noise exposure – a review, Sci. Total Environ. 435–436 (2012) 551–562.
[7] E. Öhrström, M. Björkman, R. Rylander, Noise annoyance with regard to neurophysiological sensitivity, subjective noise sensitivity and personality variables, Psychol. Med. 18 (3) (1988) 605–613.
[8] G. Belojević, E. Öhrström, R. Rylander, Effects of noise on mental performance with regard to subjective noise sensitivity, Int. Arch. Occup. Environ. Health 64 (4) (1992) 293–301.
[9] A. Fyhri, R. Klæboe, Road traffic noise, sensitivity, annoyance and self-reported health – a structural equation model exercise, Environ. Int. 35 (1) (2009) 91–97.
[10] S.A. Stansfeld, D.S. Sharp, J. Gallacher, W. Babisch, Road traffic noise, noise sensitivity and psychological disorder, Psychol. Med. 23 (4) (1993) 977–985.
[11] I. van Kamp, R.F.S. Job, J. Hatfield, M. Haines, R.K. Stellato, S.A. Stansfeld, The role of noise sensitivity in the noise-response relation: a comparison of three international airport studies, J. Acoust. Soc. Am. 116 (6) (2004) 3471–3479.
[12] L.A. Gille, C. Marquis-Favre, R. Weber, Noise sensitivity and loudness derivative index for urban road traffic noise annoyance computation, J. Acoust. Soc. Am. 140 (6) (2016) 4307–4317.
[13] D. Schreckenberg, S. Benz, C. Belke, U. Möhler, R. Guski, The relationship between aircraft sound levels, noise annoyance and mental well-being: an analysis of moderated mediation, The 12th ICBEN Congress on Noise as a Public Health Problem, 2017 Zurich, Switzerland.
[14] S.A. Stansfeld, M.P. Matheson, Noise pollution: non-auditory effects on health, Br. Med. Bull. 68 (1) (2003) 243–257.
[15] G. Bluhm, E. Nordling, N. Berglind, Road traffic noise and annoyance – an increasing environmental health problem, Noise Health 6 (24) (2004) 43–49.
[16] C. Maschke, H. Niemann, Health effects of annoyance induced by neighbour noise,

Noise Control Eng. J. 55 (3) (2007) 348–356.
[17] S.H. Park, P.J. Lee, K.S. Yang, K.W. Kim, Relationships between non-acoustic factors and subjective reactions to floor impact noise in apartment buildings, J. Acoust. Soc. Am. 139 (3) (2016) 1158–1167.
[18] S.H. Park, P.J. Lee, K.S. Yang, Perception and reaction to floor impact noise in apartment buildings: a qualitative approach, Acta Acust United Ac 102 (5) (2016) 902–911.
[19] P. Ekman, R.W. Levenson, W.V. Friesen, Autonomic nervous system activity distinguishes among emotions, Science 221 (4616) (1983) 1208–1210.
[20] M.M. Bradley, P.J. Lang, Emotion and motivation, in: J.T. Cacioppo, L.G. Tassinary, G.G. Berntson (Eds.), Handbook of Psychophysiology, Cambridge University Press, 2007, pp. 581–607.
[21] C.L. Stephens, I.C. Christie, B.H. Friedman, Autonomic specificity of basic emotions: evidence from pattern classification and cluster analysis, Biol. Psychol. 84 (3) (2010) 463–473.
[22] A.M. Weissler, R.G. Peeler, W.H. Roehll, Relationships between left ventricular ejection time, stroke volume, and heart rate in normal individuals and patients with cardiovascular disease, Am. Heart J. 62 (3) (1961) 367–378.
[23] W.B. Kannel, C. Kannel, R.S. Paffenbarger, L.A. Cupples, Heart rate and cardiovascular mortality: the Framingham Study, Am. Heart J. 113 (6) (1987) 1489–1494.
[24] P. Plant, J. Owen, M. Elliott, Early use of non-invasive ventilation for acute exacerbations of chronic obstructive pulmonary disease on general respiratory wards: a multicentre randomised controlled trial, Lancet 355 (9219) (2000) 1931–1935.
[25] K. Fox, J.S. Borer, A.J. Camm, N. Danchin, R. Ferrari, J.L.L. Sendon, et al., Resting heart rate in cardiovascular disease, J. Am. Coll. Cardiol. 50 (9) (2007) 823–830.
[26] P.J. Lang, M.M. Bradley, B.N. Cuthbert, Motivated attention: affect, activation, and action, in: P.J. Lang, R.F. Simons, M.T. Balaban (Eds.), Attention and Orienting: Sensory and Motivational Processes, Lawrence Erlbaum Associates, 1997, pp. 97–135.
[27] P. Gomez, W.A. Stahel, B. Danuser, Respiratory responses during affective picture viewing, Biol. Psychol. 67 (3) (2004) 359–373.
[28] M.E. Dawson, A.M. Schell, D.L. Filion, The electrodermal system, in: J.T. Cacioppo, L.G. Tassinary, G.G. Berntson (Eds.), Handbook of Psychophysiology, Cambridge University Press, USA, 2007, pp. 159–181.
[29] W. Boucsein, Electrodermal Activity, Springer Science & Business Media, 2012.
[30] M.M. Bradley, P.J. Lang, Affective reactions to acoustic stimuli, Psychophysiology 37 (02) (2000) 204–215.
[31] P. Gomez, B. Danuser, Affective and physiological responses to environmental noises and music, Int. J. Psychophysiol. 53 (2) (2004) 91–103.
[32] A. Tajadura-Jiménez, P. Larsson, A. Väljamäe, D. Västfjäll, M. Kleiner, When room size matters: acoustic influences on emotional responses to sounds, Emotion 10 (3) (2010) 416–422.
[33] K. Hume, M. Ahtamad, Physiological responses to and subjective estimates of soundscape elements, Appl. Acoust. 74 (2) (2013) 275–281.
[34] E. Björk, Laboratory annoyance and skin conductance responses to some natural sounds, J. Sound Vib. 109 (2) (1986) 339–345.
[35] S.A. Stansfeld, Noise, noise sensitivity and psychiatric disorder: epidemiological and psychophysiological studies, Psychol. Med. Monogr. Suppl. 22 (1992) 1–44.
[36] M. Heinonen-Guzejev, H.S. Vuorinen, H. Mussalo-Rauhamaa, K. Heikkilä, M. Koskenvuo, J. Kaprio, The association of noise sensitivity with coronary heart and cardiovascular mortality among Finnish adults, Sci. Total Environ. 372 (2) (2007) 406–412.
[37] J.K. Ryu, J.Y. Jeon, Influence of noise sensitivity on annoyance of indoor and outdoor noises in residential buildings, Appl. Acoust. 72 (6) (2011) 336–340.
[38] N.D. Weinstein, Individual differences in reactions to noise: a longitudinal study in a college dormitory, J. Appl. Psychol. 63 (4) (1978) 458–466.
[39] S.H. Park, P.J. Lee, B.K. Lee, Levels and sources of neighbour noise in heavyweight residential buildings in Korea, Appl. Acoust. 120 (2017) 148–157.
[40] ISO 10140-5, Acoustics - Laboratory Measurement of Sound Insulation of Building Elements, Part 5: Requirements for Test Facilities and Equipment, International Organization for Standardization, Geneva, Switzerland, 2010.
[41] J.Y. Jeon, P.J. Lee, J.H. Kim, S.Y. Yoo, Subjective evaluation of heavy-weight floor impact sounds in relation to spatial characteristics, J. Acoust. Soc. Am. 125 (5) (2009) 2987–2994.
[42] J. Vos, A-and C-weighted sound levels as predictors of the annoyance caused by shooting sounds, for various facade attenuation types, J. Acoust. Soc. Am. 113 (1) (2003) 336–347.
[43] P.J. Lee, M.H. Shim, J.Y. Jeon, Effects of different noise combinations on sleep, as assessed by a general questionnaire, Appl. Acoust. 71 (9) (2010) 870–875.
[44] J.R. Jennings, P.J. Gianaros, Methodology, in: J.T. Cacioppo, L.G. Tassinary, G.G. Berntson (Eds.), Handbook of Psychophysiology, 3 ed, Cambridge University Press, 2007, pp. 812–833.
[45] R. Schneider, S. Schmidt, M. Binder, F. Schäfer, H. Walach, Respiration-related artifacts in EDA recordings: introducing a standardized method to overcome multiple interpretations, Psychol. Rep. 93 (3) (2003) 907–920.
[46] L. Kaiser, Adjusting for baseline: change or percentage change? Stat. Med. 8 (10) (1989) 1183–1190.
[47] S.H. Park, P.J. Lee, Effects of floor impact noise on psychophysiological responses, Build. Environ. 116 (2017) 173–181.
[48] R.F.S. Job, Community response to noise – a review of factors influencing the relationship between noise exposure and reaction, J. Acoust. Soc. Am. 83 (3) (1988) 991–1001.
[49] H.M.E. Miedema, H. Vos, Demographic and attitudinal factors that modify annoyance from transportation noise, J. Acoust. Soc. Am. 105 (6) (1999) 3336–3344.
[50] T.J. Schultz, Synthesis of social surveys on noise annoyance, J. Acoust. Soc. Am. 64 (2) (1978) 377–405.
[51] H.M.E. Miedema, Relationship between exposure to multiple noise sources and noise annoyance, J. Acoust. Soc. Am. 116 (2) (2004) 949–957.
[52] B. Jakovljević, K. Paunović, G. Belojević, Road-traffic noise and factors influencing noise annoyance in an urban population, Environ. Int. 35 (3) (2009) 552–556.
[53] M. Kroesen, E.J. Molin, B. van Wee, Testing a theory of aircraft noise annoyance: a structural equation analysis, J. Acoust. Soc. Am. 123 (6) (2008) 4250–4260.
[54] E. Pedersen, F. van den Berg, R. Bakker, J. Bouma, Response to noise from modern wind farms in The Netherlands, J. Acoust. Soc. Am. 126 (2) (2009) 634–643.
[55] J. Watson, R. Gaind, I. Marks, Physiological habituation to continuous phobic stimulation, Behav. Res. Ther. 10 (3) (1972) 269–278.
[56] P.M. Groves, R.F. Thompson, Habituation: a dual-process theory, Psychol. Rev. 77 (5) (1970) 419.
[57] J.C. Jackson, Amplitude and habituation of the orienting reflex as a function of stimulus intensity, Psychophysiology 11 (6) (1974) 647–659.
[58] J.F. Brosschot, J.F. Thayer, Heart rate response is longer after negative emotions than after positive emotions, Int. J. Psychophysiol. 50 (3) (2003) 181–187.
[59] W. Gerin, K.W. Davidson, N.J. Christenfeld, T. Goyal, J.E. Schwartz, The role of angry rumination and distraction in blood pressure recovery from emotional arousal, Psychosom. Med. 68 (1) (2006) 64–72.

RESEARCH ARTICLE

Emotions evoked by exposure to footstep noise in residential buildings

Sang Hee Park[1], **Pyoung Jik Lee**[1]*, **Jeong Ho Jeong**[2]

1 Acoustics Research Unit, School of Architecture, University of Liverpool, Liverpool, United Kingdom, **2** Fire Safety & Building Environment System Research Team, Fire Insurers Laboratories of Korea, Yeoju-si, Gyeonggi-do, South Korea

* P.J.Lee@liverpool.ac.uk

Citation: Park SH, Lee PJ, Jeong JH (2018) Emotions evoked by exposure to footstep noise in residential buildings. PLoS ONE 13(8): e0202058. https://doi.org/10.1371/journal.pone.0202058

Editor: Michael B. Steinborn, University of Wuerzburg, GERMANY

Received: April 25, 2018

Accepted: July 26, 2018

Published: August 13, 2018

Data Availability Statement: All relevant data are within the paper and its Supporting Information files.

Funding: This research was supported by a grant (18RERP-B082204-05) from Residential Environment Research Program funded by Ministry of Land, Infrastructure and Transport of Korean Government (https://www.kaia.re.kr). The funder had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

Competing interests: The authors have declared that no competing interests exist.

Abstract

In the present study, the effect of footstep noise on emotions was investigated. This study used noise stimulus of human footsteps throughout the study. First, Korean emotion lexicons were collected from narratives of residents living in multi-family housing buildings. The lexicons were then classified into four emotion clusters, with three expressing negative emotions (anger, dislike, and pain) and the fourth depicting empathy. Since self-reported annoyance has long been investigated as one of the major non-auditory responses to noise, annoyance was measured along with affective responses in a laboratory experiment with varying noise levels. The findings revealed that the emotion and noise annoyance experienced by the participants were significantly affected by noise levels. All clusters expressing negative emotions showed strong correlations with noise annoyance, whereas that representing empathy showed the weakest correlation. Noise sensitivity and attitudes to the noise source were observed as possible moderators in emotional responses and annoyance ratings.

Introduction

Emotion is expressed in various forms such as facial expressions and language [1] and it has been commonly investigated by analysing physical and linguistic expressions. Physical analyses of facial expressions and physiological responses [2–6] are useful for identifying emotions of which the perceiver is unaware [7]. However, subtle emotional feelings cannot be determined through physical analyses [8] because of the influences of psychological or physical activities [9]. As another approach, emotion can be studied by examining linguistic expressions. Russell [10] plotted lexicons on a circular model comprising two dimensions (pleasantness and arousal) and showed the interrelationships between the emotions reported. A few studies have also attempted to group emotions on the dimensional model based on their psychological conditions [11–14]. Fehr and Russell [11] conducted series of study to group emotion lexicons under a certain number of prototypes and to validate the grouping procedure. Likewise, Ortony et al. [12] collected a number of lexicons from the literature on emotions and categorised them into eight groups, including physical, affective, and cognitive states. These eight categories were then tested by asking people to rate the emotion lexicons; it was found that the most discriminable categories were affective, cognitive, external, and bodily conditions

[13]. Instead of using the dimensional model, Shaver et al. [14] examined the hierarchical structure of emotion concepts and specified prototypes of the emotion categories. They collected 213 emotion lexicons and categorised them into the six groups of love, joy, surprise, anger, sadness, and fear based on subjective ratings [14].

Emotion is a response to a stimulus as well as a quality of excitement that accompanies instinctive reactions [15]. In order to understand the specific emotions provoked by stimuli, different types of stimuli have been used in laboratory experiments. Among them, the most commonly used stimuli are visual images, such as photographs and video clips. For example, Greenwald et al. [16] measured emotions and physiological responses after the presentation of photographic images evoking different emotions (e.g. happy baby or angry face). Acoustic stimuli have also been used to investigate emotions, with variations in sound source and acoustic characteristics. In particular, a majority of acoustic stimuli include outdoor noises such as environmental noise. From a group discussion conducted with participants who were exposed to different noises consisting of environment and neighbour noises, Grimwood [17] reported that three levels of emotional reactions are caused by noises heard at home. Namba et al. [18] developed adjective lexicons in five different languages in order to describe subjective impressions to acoustic stimuli, including road traffic and construction noises. Using cluster analyses, they found that the road traffic and construction noises were grouped together and that the lexicon 'unpleasing' was closely tied to 'annoying' and 'noisy' in most languages [18]. Gomez and Danuser [19] presented 16 environmental noises for 30 seconds in order to evoke broad emotional responses with varying affective valence and arousal. Hume and Ahtamad [20] also used 18 sound clips with a duration of eight seconds each, to investigate pleasantness and arousal, and a majority of the sounds were environmental noises such as traffic and construction noises. In contrast to research on environmental noise, research on emotional responses evoked by indoor noise, such as neighbour noise, is scarce. Although Grimwood [17] investigated emotions related to neighbour noise when studying environmental noise, a majority of the participants were previously exposed to noise from roads, railways, and building works; thus, the emotional reactions to neighbour noise alone were not determined. Stansfeld et al. [21] also pointed out that noise from neighbours is a major source of annoyance and emotional responses in an urban environment; however, its impact has not been studied adequately.

Noise is hazardous to people's well-being [22]. In particular, exposure to neighbour noise causes annoyance and disturbs activities [23–25]; thus, most studies on neighbour noise have mainly focused on annoyance and sleep disturbance. Raw and Oseland [23] analysed subjective ratings of noise disturbance in conversion flats and reported that noise from upstairs causes sleep disturbance. Through a questionnaire survey and laboratory experiment, Ryu and Jeon [24] explored annoyance caused by indoor noise and the effects of noise sensitivity on annoyance ratings. Park et al. [25] examined the relationship of annoyance caused by floor impact noise with non-acoustic factors such as disturbance and reported that noise annoyance significantly influences health-related complaints. The health risks induced by neighbour noise have been previously reported by several researchers [22, 26, 27]. Additionally, recent laboratory experiments [28, 29] have investigated physiological responses caused by floor impact noise, which is one type of neighbour noise, but emotional reactions were not assessed. Furthermore, neighbour noise results in disputes [30] and even crimes between neighbours [31]. Stokoe and Hepburn [30] analysed discourses of dispute mediation interviews, and the interview extracts clearly showed how residents react to and perceive their neighbours and their noise. Specifically, the interviewees who had disputes with their neighbours described their neighbours as unreasonable, irrational, unaccountable, and distressing [30]. Park [31] reported that the number of registered noise complaints had soared and that there were four murder cases caused by neighbour noise in 2013 in Korea. Park [31] also claimed that such crimes are often retaliatory crimes caused by emotional reactions. Therefore, it is necessary to explore the emotional responses evoked by floor impact noise because annoyance alone may not adequately explain noise-related disputes and crimes.

The above discussion leads us to the following research questions: (1) What kinds of emotional responses other than annoyance are evoked by neighbours' footstep noise? (2) How are emotional responses related to acoustic and non-acoustic variables such as noise level and noise sensitivity? (3) Can social problems (e.g. neighbour disputes and crimes) be further explained by emotional responses to footstep noise? This study aimed to answer the research questions through online questionnaire surveys and a laboratory experiment. Emotion lexicons on footstep noise were collected from a number of residents' narratives, which were clustered into different groups by a series of questionnaire surveys. A laboratory experiment was conducted to test the clustered emotional groups with varying sound pressure levels. Participants with different noise sensitivity scores took part in the experiment.

Emotion classification

Lexicon collection

Korean emotion lexicons were collected from narratives of residents living in multi-family housing buildings in South Korea. First, interview transcripts from a previous study [32] were used to collect emotion lexicons regarding footstep noise. The interviews were carried out with 14 residents (five males and nine females) living in multi-family housing buildings; their ages ranged from 21 to 55 years and the length of residency in their houses ranged from 10 months to 15 years [32]. Expressions towards their neighbours' footstep noise, such as 'bothered', 'painful', and 'tolerable', were identified in the transcripts. The second source of lexicons was online communities. As listed in Table 1, posts on a total of 18 different online communities

Table?1. Online communities from which emotion lexicons were collected.

Community topic	No.	Launched date	Number of community members[a]	Number of collected posts
General	1	2004.02.26	3,002,761	754
	2	2003.07.11	2,639,542	1,452
	3	2007.03.03	193,842	893
	4	2009.12.31	162,714	230
	5	2006.03.30	126,532	64
	6	2006.08.26	23,813	197
	7	2012.11.19	12,197	41
	8	2004.02.22	5,425	34
	9	2012.10.02	3,339	12
For residents in multi-family housing buildings	10	2005.10.14	20,371	3,867
	11	2010.06.15	4,430	765
	12	2012.10.25	3,816	691
	13	2014.05.12	2,282	192
	14	2011.07.01	1,758	245
	15	2016.07.11	829	96
	16	2014.06.14	645	68
	17	2011.01.11	511	129
	18	2011.12.28	150	34

[a] Date of the number counting: 28/12/2017

https://doi.org/10.1371/journal.pone.0202058.t001

were searched. Nine online communities concerned general topics, such as food, sports, and children, so the members were not restricted to residents of multi-family housing buildings. On the other hand, the other nine communities were limited to residents living in multi-family housing buildings. Lexicons about footstep noise were collected by using the keywords listed in Table 2. The two words 'noise' and 'sound' were used as the main keywords, and seven sub-keywords, such as 'floor' and 'neighbour', were introduced. First, online posts containing a combination of one main keyword and at least one sub-keyword were retrieved. Posts on other types of neighbour noise (e.g. piano sounds, voice, chair scraping noise, etc.) were then filtered out. All lexicons were screened based on published research on Korean emotion lexicons [33–36]. After this process, a total of 120 lexicons expressing emotions towards neighbours' footstep noise were extracted.

Lexicon sampling and clustering: The survey study

The 120 lexicons collected from the interview transcripts and online communities were used as a primary source in the surveys (Survey I and Survey II). The lexicons were sampled and clustered through the surveys. Both surveys were conducted on an online survey platform (QuestionPro). The study complied with all terms of service for the website. The survey invitation was posted on public online communities, potential respondents were then contacted by email and asked to complete the online questionnaire via an embedded link. The invitations clearly stated the following details of the study: (1) the aim of this study is to explore emotions towards indoor noise, (2) respondents should have normal-hearing and be residents of multi-family housing buildings, and (3) respondents need to use headphones as sounds will be presented in the survey. These instructions were again presented on the first page of each survey, along with a consent form. Only those who provided their consent by clicking "I agree" on the first screen were directed to the questionnaire.

Noise stimulus. Footstep noises made by a child and an adult were played during the survey. This noise clip was recorded and used in a previous laboratory experiment [28]. The original recording was 10-second long with dominant sound energies at low-frequencies of below 125 Hz. However, the reproduction of low-frequency components was affected by the hearing device used by the respondents.

Lexicon sampling: Survey I. In the online questionnaire, the 120 lexicons were listed randomly. The respondents were asked to listen to the noise carefully and to choose lexicons that represented their emotions towards the stimulus. The noise stimulus was played continuously until the respondents completed the questionnaire. A total of 133 residents (53 males and 80 females) volunteered to take part in Survey I. Sixty lexicons were chosen based on the frequencies, and they were used in the subsequent survey.

Table 2. Keywords used for searching online postings. Korean lexicons used in the study can be found from one of supporting materials (S1 Table).

Category	Keywords
Main keyword	noise sound
Sub-keyword	floor between floors; inter-floor neighbour upstairs foot; footsteps running; jumping walking

https://doi.org/10.1371/journal.pone.0202058.t002

Lexicon clustering: Survey II. Sixty lexicons chosen from Survey I were randomly presented to the respondents in Survey II. As in Survey I, respondents evaluated the appropriateness of the lexicons for the noise stimulus. The respondents were asked to carefully listen to the noise and to rate the extent to which each lexicon was appropriate for expressing their emotions towards the stimulus, using a 5-point scale (1 = '*not at all*' and 5 = '*extremely*'). As listed in Table 3, a total of 89 respondents (43 males and 46 females) took part in Survey II.

In the present study, the cluster analysis method was adopted to classify the lexicons based on the respondents' ratings. A hierarchical clustering analysis was performed based on the average linkage algorithm and Euclidean distances between lexicons using SPSS for Windows (version 22.0, SPSS Inc. Chicago, IL). Based on the results, 60 lexicons were classified into four clusters (E1, E2, E3, and E4). Emotion lexicons in E1 were mainly related to 'ANGER' (e.g. angry, vengeful), those in E2 mostly expressed 'DISLIKE' (e.g. unpleasant, bothered), and those in E3 mainly expressed 'PAIN' (e.g. painful, distressing). Finally, emotion lexicons expressing 'EMPATHY' were grouped in E4 (e.g. bearable, indifferent). As presented in Table 4, E1 had the most lexicons, with 21 lexicons. This may imply that exposure to footstep noise predominantly induces emotions related to anger. As listed in Table 5, the top 20 lexicons were chosen based on the mean scores and they were used in the subsequent laboratory study. There were five, six, four, and five lexicons in E1, E2, E3, and E4, respectively.

Laboratory experiment for the evaluation of emotions

Methods

Noise stimuli. The same noise stimulus (i.e. footstep noise) used in the online surveys was used in the laboratory experiment. As mentioned earlier, it had dominant sound pressure levels at low-frequencies. The noise levels of the stimulus were edited in terms of the A-weighted maximum noise level (L_{AFmax}), to cover a range from 30 to 60 dB in 5 dB intervals; thus, seven noise stimuli were created. The duration of the stimuli was set to 80 seconds. The 10-second long noise clips were edited to be repeated for 80 seconds.

Apparatus. The laboratory experiment was conducted in a sound-proof room with a low background noise level (~25 dBA) in the Fire Insurers Laboratories of Korea (FILK). The floor area was about 35.7 m^2 (4.8 m × 7.43 m), which simulates the area of a living room in most common apartments. There was a sofa in the middle of the space, a television in front of the sofa, and an air-conditioner on the front wall. The volume of the room was 93.8 m^3 (4.8 m × 7.43 m × 2.63 m), and the shape of the room was rectangular. Most surfaces were covered with sound absorbers, and the reverberation time of the room was about 0.21 seconds at 1 kHz.

Table 3. Information about the respondents in Survey II ($n = 89$).

		Number of participants
Age group	20s	4
	30s	10
	40s	49
	50s	21
	60s or over	5
Gender	Male	43
	Female	46
Past experience of neighbour disputes regarding noise	Yes	50
	No	39

https://doi.org/10.1371/journal.pone.0202058.t003

Table 4. Sixty lexicons grouped in four clusters.

Emotion cluster	Number of lexicons	Emotion prototype	Sample lexicons
E1	21	ANGER	get angry, get enraged, detestable, resent, fury, vengeful
E2	10	DISLIKE	awkward, bothered, irritated, unpleasant, unwelcome
E3	16	PAIN	my head is throbbing, feeling sick, painful, suffering, tired
E4	13	EMPATHY	bearable, just being patient, no reason to get irritated, tolerable

https://doi.org/10.1371/journal.pone.0202058.t004

Noise stimuli were reproduced using loudspeakers and a subwoofer in order to replicate real footstep noise. Sounds above 63 Hz were presented via one loudspeaker (Genelec 8050A), while low-frequency sounds below 63 Hz were presented via the subwoofer (Velodyne Micro-Vee). A low-pass filter with a cut-off frequency of 63 Hz in the octave band was applied to the sounds played via the subwoofer. The loudspeaker and subwoofer were placed in front of the participants, with the loudspeaker mounted at 1.2 m above the floor to simulate the noise from upstairs neighbours. An additional loudspeaker was used to present ambient noise at 31 dBA.

Participants. In order to assess statistical power, the sample size in previous research was referred to. Park and Lee [29] previously measured self-rated annoyance when their participants (n = 21) were presented with floor impact noise stimuli and found strong correlations between annoyance and noise level (r = 0.95). With this effect size, the sample size was estimated using G*Power to obtain 80% power with $\alpha = .05$ [37, 38]. The results showed that a total sample of n = 34 was needed. Based on this estimation, it was aimed to recruit a minimum

Table 5. Twenty lexicons used in the laboratory study. Korean lexicons used in the study can be found from one of supporting materials (S1 Table).

Emotion cluster	Median	Mean	SD	Lexicon
E1	4	3.4	1.3	unhappy
	3	3.2	1.3	detestable
	4	3.2	1.3	can't understand
	3	3.0	1.4	get enraged
	3	2.9	1.3	ridiculous
E2	4	3.7	1.2	bothered
	4	3.6	1.3	unwelcome
	4	3.5	1.3	dislike
	4	3.4	1.3	get on my nerves
	4	3.4	1.3	awkward
	3	3.3	1.3	vexed
E3	3	3.3	1.4	suffering
	4	3.2	1.3	tired
	4	3.2	1.3	my head is throbbing
	3	3.0	1.4	painful
E4	3	2.9	1.3	bearable
	3	2.9	1.2	just being patient
	3	2.9	1.3	tolerable
	3	2.8	1.4	no reason for discomfort
	2	2.8	1.4	think of it as usual

https://doi.org/10.1371/journal.pone.0202058.t005

of 35 participants and a total of 41 Korean participants (22 males and 19 females) took part in the study. A participant information sheet and a written consent form were provided to the participants upon arrival, and only those who provided their consent participated in the study. None of the participants reported hearing disabilities. Before the experiment, each participant was asked to answer several questions about demographic information, noise sensitivity, and attitude towards their upstairs neighbours. Noise sensitivity was evaluated using 21 questions [39], and attitude towards their upstairs neighbours was assessed using six questions. The questions can be found from one of supporting materials (S1 File). As shown in Table 6, the majority of the participants were in their 30s and 40s. Half of them had one or more children, and more than half reported that they had lived in their current dwelling for less than five years. In order to observe a clear difference between the low and high noise-sensitivity groups, participants with moderate noise sensitivity levels were excluded from the grouping. First, participants' noise sensitivity scores were divided into five groups using 20th, 40th, 60th, and 80th percentiles from the observed mean score distributions as cut-off points. Second, the middle range between the 40th and 60th percentiles was excluded. Thus, the low and high noise sensitivity groups included individuals with scores lower than the 40th percentile and scores higher than the 60th percentile, respectively. The mean noise sensitivity score of the low group was 79.6 (std. deviation = 6.3), and that of the high group was 102.1 (std. deviation = 6.4). The low and high noise-sensitivity groups had 15 and 16 participants, respectively. Similarly, positive and negative attitude groups were also divided while excluding the middle range between the 40th and 60th percentiles. Those whose attitude scores were lower than 16 were included in the negative attitude group, while those who reported an attitude score higher than 18 were included in the positive attitude group. The mean attitude score of the positive group was 23.4 (std. deviation = 3.6), and that of the negative group was 13.6 (std. deviation = 1.6). The positive and negative attitude groups contained 15 and 16 participants, respectively.

Procedure. A laboratory experiment was conducted to investigate the effect of noise levels on emotions in terms of lexicons. The experiment was designed based on the hypothesis that noise levels would influence emotion and annoyance ratings. Each participant was guided to sit on a sofa in the middle of the room in a comfortable position, and he/she responded to questionnaires on emotion and annoyance ratings while noise stimuli were presented for 80

Table 6. Information about the participants of the laboratory study ($n = 41$).

		Number of participants
Age group	20s	5
	30s	13
	40s	20
	50s	3
Gender	Male	22
	Female	19
Child(ren) at home	Yes	20
	No	21
Length of residency	less than 1 year	7
	1–3 years	12
	3–5 years	13
	5–10 years	1
	10–15 years	8
Past experience of making noise complaints	No	28
	Yes	13

https://doi.org/10.1371/journal.pone.0202058.t006

seconds each. All the stimuli and lexicons listed on the questionnaires were presented randomly to minimise the order effect.

The participants were asked to rate 20 emotion lexicons on 7-point scales (0 = '*not at all*' and 6 = '*extremely*') according to the following instruction: 'Please rate the extent to which each lexicon is appropriate for expressing your emotions towards the noise you are currently hearing'. Participants were also asked to rate the noise annoyance perceived due to each of the noise stimuli. Participants were provided with the instruction 'Please rate noise annoyance perceived by the noise you are currently hearing'. Participants used a 7-point scale (0 = '*not at all*' and 6 = '*extremely*') to indicate their level of annoyance. The ratings of emotions and noise annoyance were then translated into a scale from 0 to 100 for assessments of percentage of high emotion rating (%HE) and percentage of highly annoyed (%HA). Both measures were defined as the percentages of emotion and annoyance responses which exceeded a certain cut-off point. Schultz [40] used a cut-off of 72 in his synthesis to define %HA and the same cut-off point was chosen in the present study for both %HE and %HA.

Participants were instructed to consider everything that they heard and felt during noise exposure. Since 10 seconds of footstep noises were repeated over an 80-second period, participants could listen to the stimuli several times when they were responding to the questions. Prior to the commencement of the experiment, each participant attended a trial session to familiarise themselves with the experimental setting in which they responded using 7-point numerical scales.

This study was approved by the School of the Arts Committee on Research Ethics, University of Liverpool. A local ethics committee does not exist; thus, approval was obtained from the local institution where the laboratory experiments were conducted.

Data analysis. Statistical analyses were performed using SPSS for Windows (version 22.0, SPSS Inc. Chicago, IL). The main effects of noise levels on the participants' responses were analysed using the repeated measures analysis of variance (ANOVA), and group differences were examined using the Mann-Whitney U test and independent samples t-test. In the present study, p values of less than 5% ($p < 0.05$) were considered as statistically significant. The data used for the statistical analysis can be found from one of supporting materials (S2 File).

Results

Noise levels caused significant effects on all emotion and annoyance ratings. In addition, the interaction effect between noise levels and noise sensitivity showed significant effects on ratings, while no interaction effect was found between noise levels and attitudes. The effects of noise level, noise sensitivity, and attitudes on ratings are listed in Table 7.

The high noise-sensitivity group showed greater emotion ratings for E1–E3 than the low noise-sensitivity group (Fig 1). The differences in ratings between the two groups were the smallest at the lowest noise level and they increased with an increase in noise level. Opposite tendencies were found in E4, showing that participants who were sensitive to noise tended to assign lower E4 ratings than the less sensitive participants. The results of the Mann-Whitney U tests confirmed that the emotion ratings for the high noise-sensitivity group were significantly distinct from those for the low noise-sensitivity groups, at all noise levels. Similar tendencies were found between the positive and negative attitude groups (Fig 2). Significantly different emotion ratings were found between the positive and negative attitude groups at most noise levels.

Fig 3 presents the noise annoyance ratings of the noise-sensitivity and attitude groups as a function of noise level. It was found that noise annoyance ratings increased with sound pressure level and that the ratings of the high noise-sensitivity group were greater than those of the

Table 7. Results of repeated-measures ANOVAs, with noise level as within-subjects factor, and noise-sensitivity groups and attitude groups as between-subjects factors.

Measurement	Source	df	F	Sig.	Partial Eta Squared
E1	Within-Subjects				
	Noise level	6	147.41	.000	.88
	Noise level x Noise-sensitivity group	6	11.28	.000	.36
	Noise level x Attitude group	6	1.35	.239	.06
	Error(Noise level)	120			
	Between-Subjects				
	Intercept	1	1096.16	.000	.98
	Noise-sensitivity group	1	176.72	.000	.90
	Attitude group	1	0.06	.804	.00
	Error	20			
E2	Within-Subjects				
	Noise level	4	115.44	.000	.85
	Noise level x Noise-sensitivity group	4	13.11	.000	.40
	Noise level x Attitude group	4	1.04	.390	.05
	Error(Noise level)	73			
	Between-Subjects				
	Intercept	1	1079.61	.000	.98
	Noise-sensitivity group	1	125.84	.000	.86
	Attitude group	1	0.41	.527	.02
	Error	20			
E3	Within-Subjects				
	Noise level	6	134.87	.000	.87
	Noise level x Noise-sensitivity group	6	12.29	.000	.38
	Noise level x Attitude group	6	1.16	.332	.06
	Error(Noise level)	120			
	Between-Subjects				
	Intercept	1	969.83	.000	.98
	Noise-sensitivity group	1	130.51	.000	.87
	Attitude group	1	0.00	.991	.00
	Error	20			
E4	Within-Subjects				
	Noise level	3	133.01	.000	.87
	Noise level x Noise-sensitivity group	3	5.81	.002	.23
	Noise level x Attitude group	3	0.50	.675	.03
	Error(Noise level)	58			
	Between-Subjects				
	Intercept	1	632.73	.000	.97
	Noise-sensitivity group	1	95.95	.000	.83
	Attitude group	1	0.62	.442	.03
	Error	20			
Annoyance	Within-Subjects				
	Noise level	6	272.56	.000	.93
	Noise level x Noise-sensitivity group	6	14.94	.000	.43
	Noise level x Attitude group	6	0.61	.722	.03
	Error(Noise level)	120			
	Between-Subjects				

(*Continued*)

Table 7. (Continued)

Measurement	Source	df	F	Sig.	Partial Eta Squared
	Intercept	1	1261.79	.000	.98
	Noise-sensitivity group	1	64.53	.000	.76
	Attitude group	1	2.38	.139	.11
	Error	20			

https://doi.org/10.1371/journal.pone.0202058.t007

low noise-sensitivity group. The high noise-sensitivity group showed steeper changes in noise annoyance than the low noise-sensitivity group. The results of the Mann-Whitney U tests indicated that the differences between the sensitivity groups were statistically significant at all levels, except for those at 30 dBA. Similar to the emotion ratings, the differences in noise annoyance ratings between the noise-sensitivity groups were more significant with louder noise. However, for the attitude groups, there was no significant difference between the positive and negative attitude groups.

The relationships between the ratings of emotions (E1–E4) and noise annoyance for the low and high noise-sensitivity groups are presented in Fig 4. The E1–E3 clusters containing negative emotions had positive correlations with noise annoyance, whereas the relationship

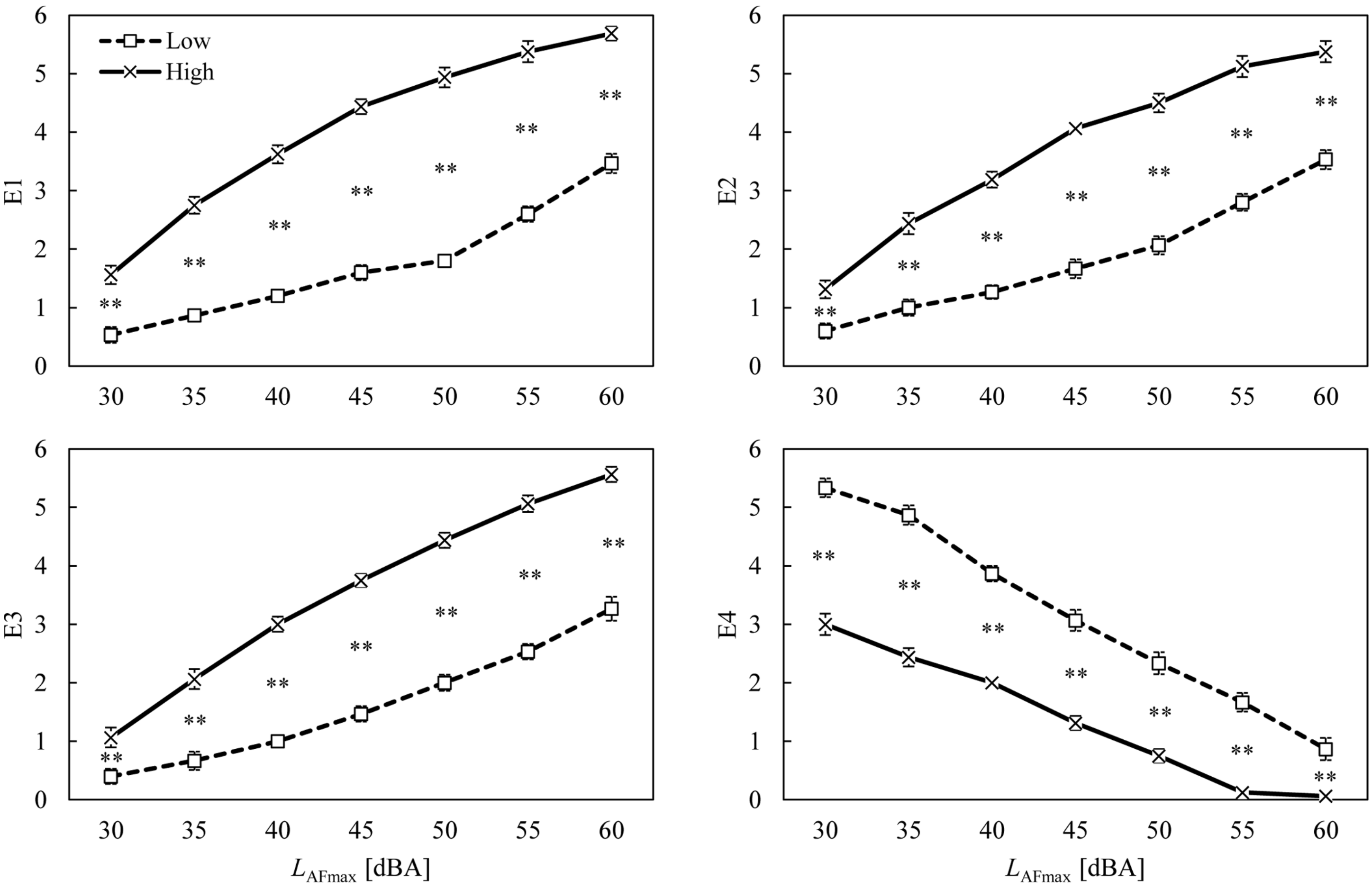


Fig 1. Ratings of perceived emotions for low (□) and high (×) noise-sensitivity groups as a function of noise level. Error bars indicate standard errors. Asterisks indicate significant differences between means according to the Mann-Whitney U test ($^{*}p < 0.05$ and $^{**}p < 0.01$).

https://doi.org/10.1371/journal.pone.0202058.g001

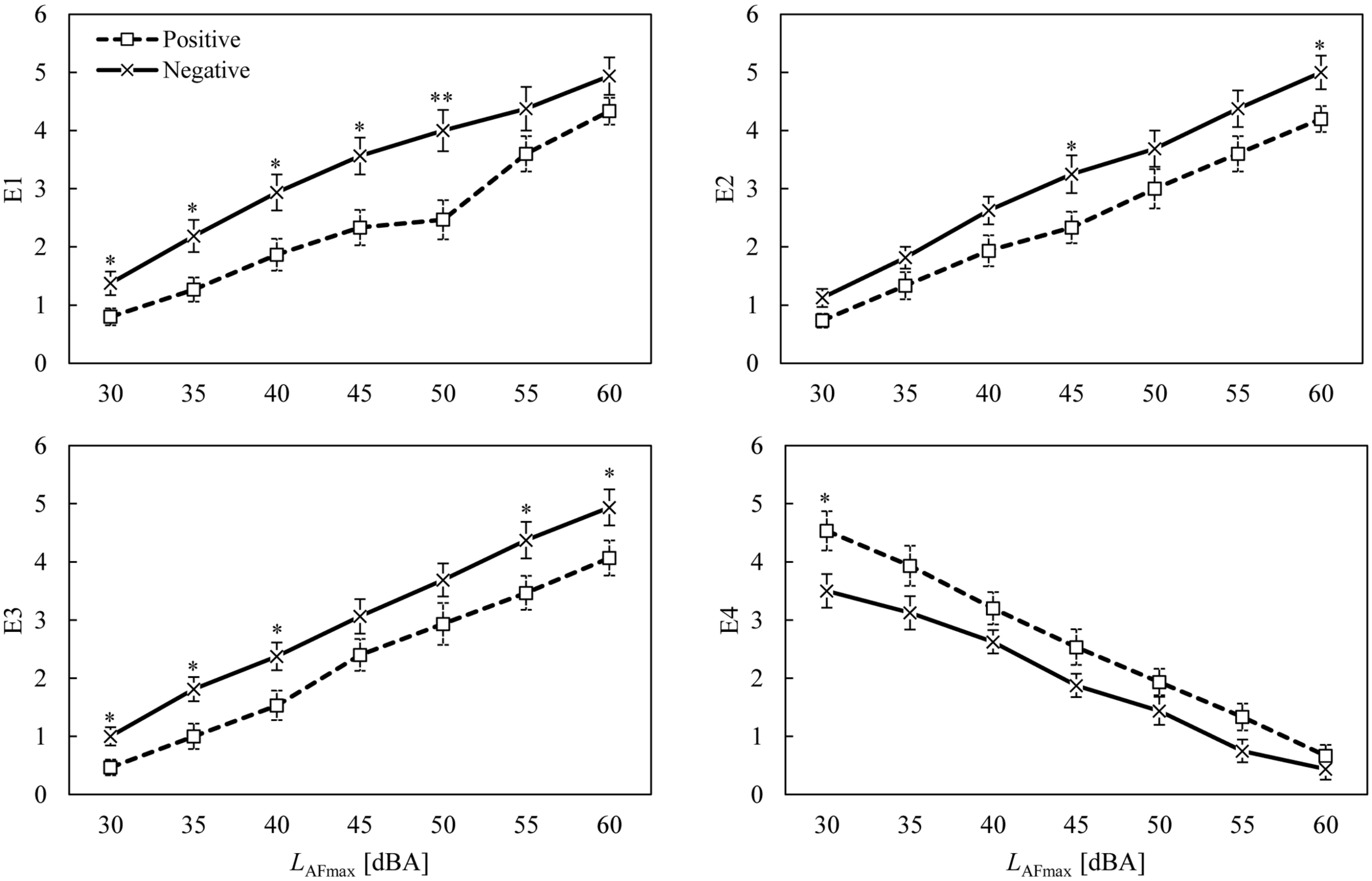


Fig 2. Ratings of perceived emotions for positive (□) and negative (×) attitude groups as a function of noise level. Error bars indicate standard errors. Asterisks indicate significant differences between means according to the Mann-Whitney U test ($^*p < 0.05$ and $^{**}p < 0.01$).

https://doi.org/10.1371/journal.pone.0202058.g002

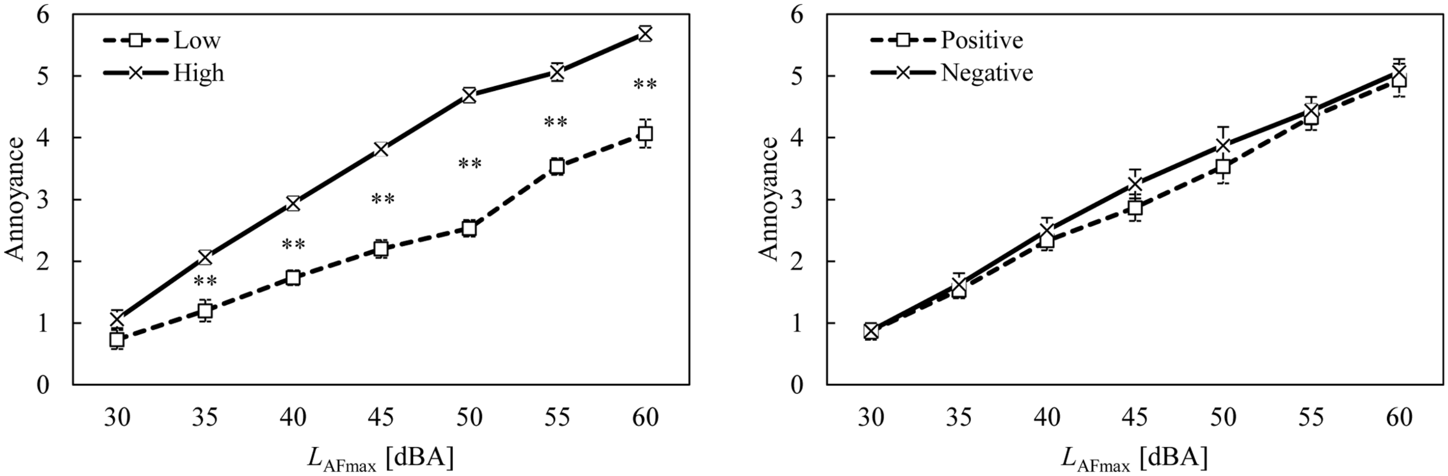


Fig 3. Ratings of noise annoyance for low (□) and high (×) noise-sensitivity groups and positive (□) and negative (×) attitude groups as a function of noise level. Error bars indicate standard errors. Asterisks indicate significant differences between means according to the Mann-Whitney U test ($^*p < 0.05$ and $^{**}p < 0.01$).

https://doi.org/10.1371/journal.pone.0202058.g003

between E4 and noise annoyance was negative. Fig 4 illustrates the differences between the low and high noise-sensitivity groups in terms of the range of mean ratings. For example, the ratings of E1 for the high noise-sensitivity group ranged from 1.1 to 5.1, whereas those for the low noise-sensitivity group ranged from 0.5 to 4.0. Similar patterns were observed in the relationships between the four emotion clusters (E1–E4) and noise annoyance for the positive and negative attitude groups (Fig 5). The ratings of the three clusters on negative emotions (E1–E3) were positively correlated with noise annoyance, whereas that of E4 showed negative relationship with noise annoyance. The correlation coefficients for the relationship between the ratings of emotions and noise annoyance for the positive and negative groups were similar to those for the noise-sensitivity groups.

Correlations between emotions and noise annoyance with noise level and annoyance are presented in Table 8. It also presents correlations tested with all participant responses, as well as noise sensitivity and attitude groups' responses. It was found that all emotions and annoyance ratings showed significant correlations with noise level. It also shows that all emotions showed significant correlations with annoyance. E4 was the only variable with negative correlations and much lower coefficients than the other variables. This indicates that negative emotions have a greater association with increased noise levels, and they are more useful for understanding noise annoyance than emotion regarding empathy. Higher correlation

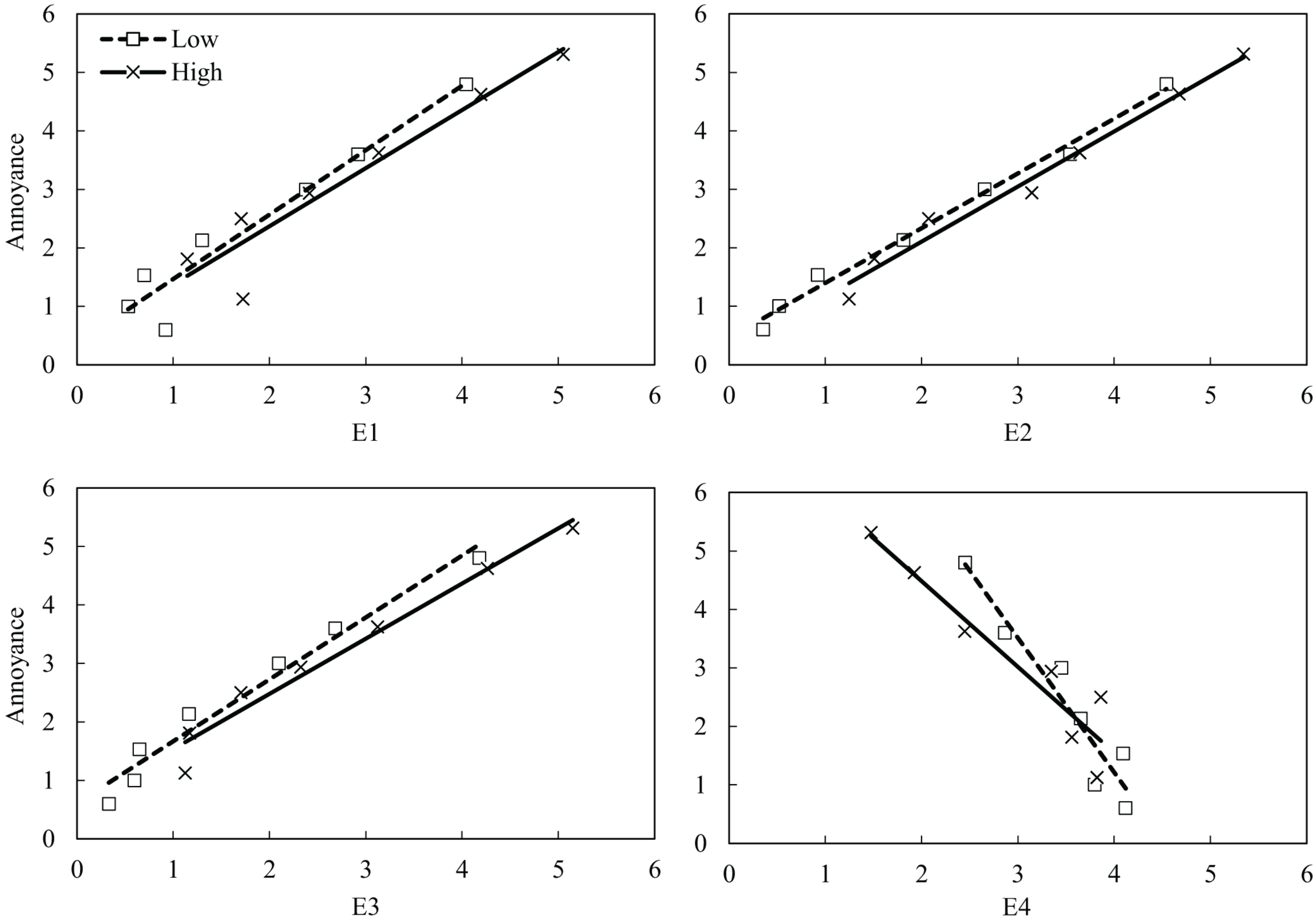


Fig 4. Relationships between noise annoyance and perceived emotions for low (□) and high (×) noise-sensitivity groups.

https://doi.org/10.1371/journal.pone.0202058.g004

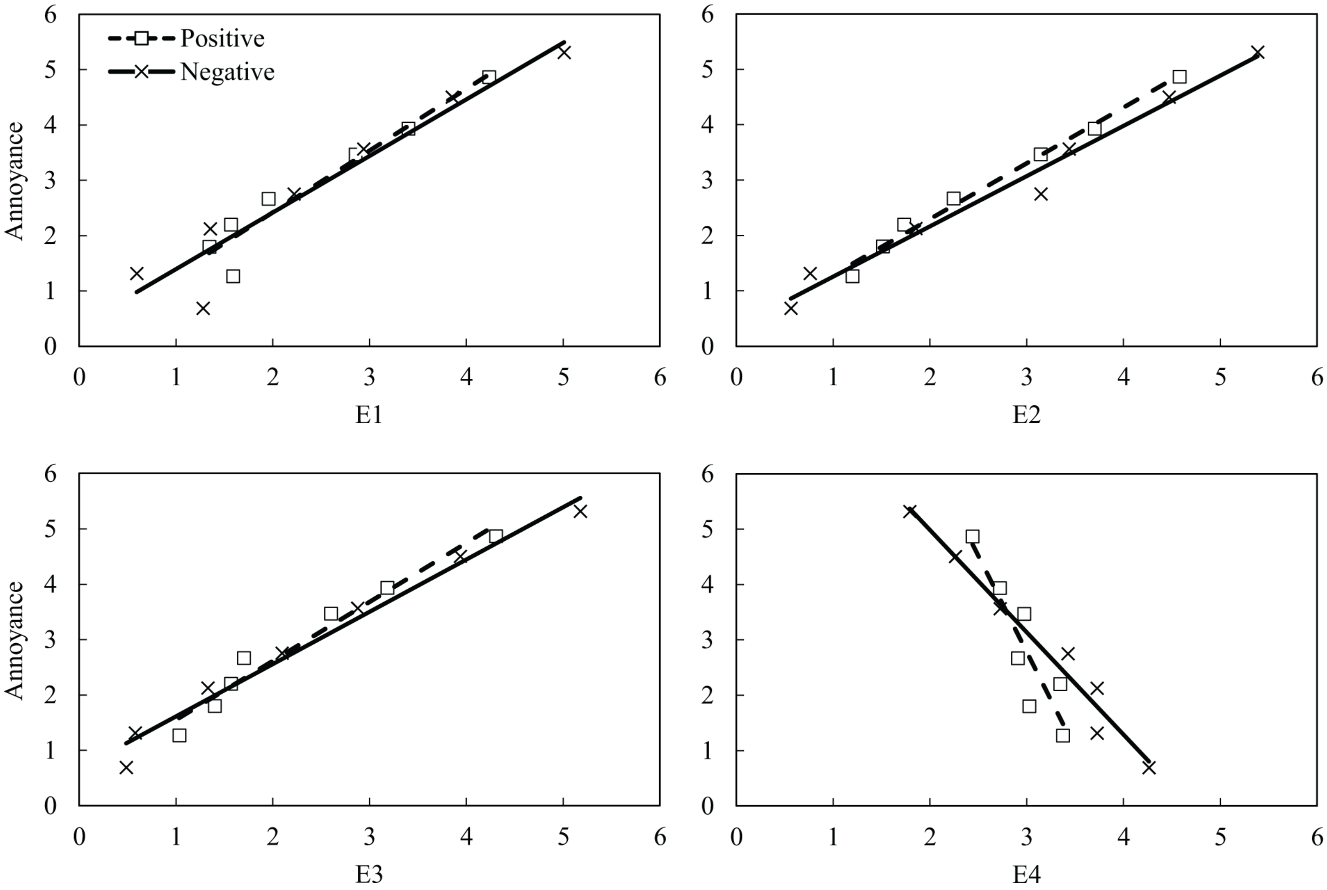


Fig 5. Relationships between noise annoyance and perceived emotions for positive (□) and negative (×) attitude groups.

https://doi.org/10.1371/journal.pone.0202058.g005

coefficients were found from the high noise-sensitivity group and negative attitude group compared with the low noise-sensitivity group and positive attitude group. However, Fisher's r to z transformation showed that the correlation coefficients between groups were not significantly different.

The percentages of high emotion ratings for the four clusters (%HE1–%HE4) as a function noise level are plotted in Figs 6 and 7. Notable differences between the noise-sensitivity and attitude groups were observed for all the emotion clusters. For the high noise-sensitivity group (Fig 6), the percentage of highly rated E1 (%HE1) started to increase above 30 dB, and it reached 100% at 45 dB. However, the low noise-sensitivity group's %HE1 remained at 0% until 55 dB. This indicates that participants who were sensitive to noise chose rating scores above the cut-off point (5 or 6 on a 7-point numerical scale), even at low noise levels such as 35 dB. However, no one in the low noise-sensitivity group selected 5 or 6 even at 55 dB. Similar tendencies were found in the E2, E3, and E4, showing huge differences between the noise-sensitivity groups. For example, when L_{AFmax} was at 50 dB, the %HE2 and %HE3 were 100% for the high noise-sensitivity group, whereas they were 0% for the low noise-sensitivity group. Although the tendencies are less clear than those for the noise-sensitivity groups, the %HE1–%HE3 of the negative attitude groups were consistently higher and the %HE4 was lower than those of the positive attitude group (Fig 7).

Fig 8 compares the percentages for those who were highly annoyed (%HA) in the noise-sensitivity and attitude groups. For the high noise-sensitivity group, the percentage of those who

Table 8. Correlations of emotions (E1–E4) and noise annoyance with (a) noise level and (b) annoyance; tested between all participants, noise-sensitivity groups, and attitude groups.

(a)			E1	E2	E3	E4	Annoyance
All participants (n = 41)		Noise level	.63**	.70**	.64**	-.37**	.77**
Noise-sensitivity group	Low (n = 15)	Noise level	.64**	.74**	.64**	-.26**	.80**
	High (n = 16)	Noise level	.67**	.74**	.70**	-.43**	.77**
Attitude group	Positive (n = 15)	Noise level	.52**	.59**	.52**	-.17*	.70**
	Negative (n = 16)	Noise level	.72**	.80**	.74**	-.36**	.86**
(b)			E1	E2	E3	E4	Annoyance
All participants (n = 41)		Annoyance	.87**	.88**	.89**	-.66**	1
Noise-sensitivity group	Low (n = 15)	Annoyance	.87**	.87**	.81**	-.46**	1
	High (n = 16)	Annoyance	.81**	.85**	.78**	-.56**	1
Attitude group	Positive (n = 15)	Annoyance	.83**	.88**	.82**	-.45**	1
	Negative (n = 16)	Annoyance	.88**	.89**	.84**	-.44**	1

* $p < 0.05$;

** $p < 0.01$

Sample size (n) of each group was the same for all tested correlations.

https://doi.org/10.1371/journal.pone.0202058.t008

were highly annoyed (%HA) increased sharply in the region between 40 dB and 45 dB, and it then reached 100% at 50 dB. In contrast, the %HAs of the low noise-sensitivity group remained at 0% until 45 dB, and it increased slowly above 50 dB. For the attitude groups, the %HA of the positive attitude group increased more slowly than that of the negative attitude group.

Discussion

Lexicon clusters

As described by Roseman et al. [41], emotion is caused by the way in which a person interprets a situation (i.e. appraisals). For instance, people feel pain or fear if they believe that they will not be able to resolve a negative situation satisfactorily [42]. The four emotion clusters evoked by neighbour noise may also have had a relationship with potential appraisals. The first cluster, E1, which contains the largest number of lexicons, was related to anger and hostility, mainly towards the noise source (i.e. upstairs neighbours). Anger is caused by a blocked 'goal' [43], which may cause the perception of the absence of a reward or presence of a punishment [44]. The term 'goal' is referred to as an outcome that is personally significant [45, 46]. If the noise of neighbours' footsteps has frequently disturbed residents' significant activities, such as sleeping and studying (i.e. 'goal') [32], these experiences might lead to anger-related emotions. Anger is also linked with a specific appraisal called 'other-blame', which is a belief that the unpleasant situation was wrongly caused by someone or something [45]. Indeed, it may be argued that residents who appraise the noise event as their upstairs neighbours' fault or carelessness would perceive anger-related emotions towards their neighbours. The appraisal of 'other-blame' contains a belief that the person causing the event acted in an improper or unfair manner [14, 44]; thus, residents might perceive anger-related emotions towards their neighbours who do not act appropriately regarding the

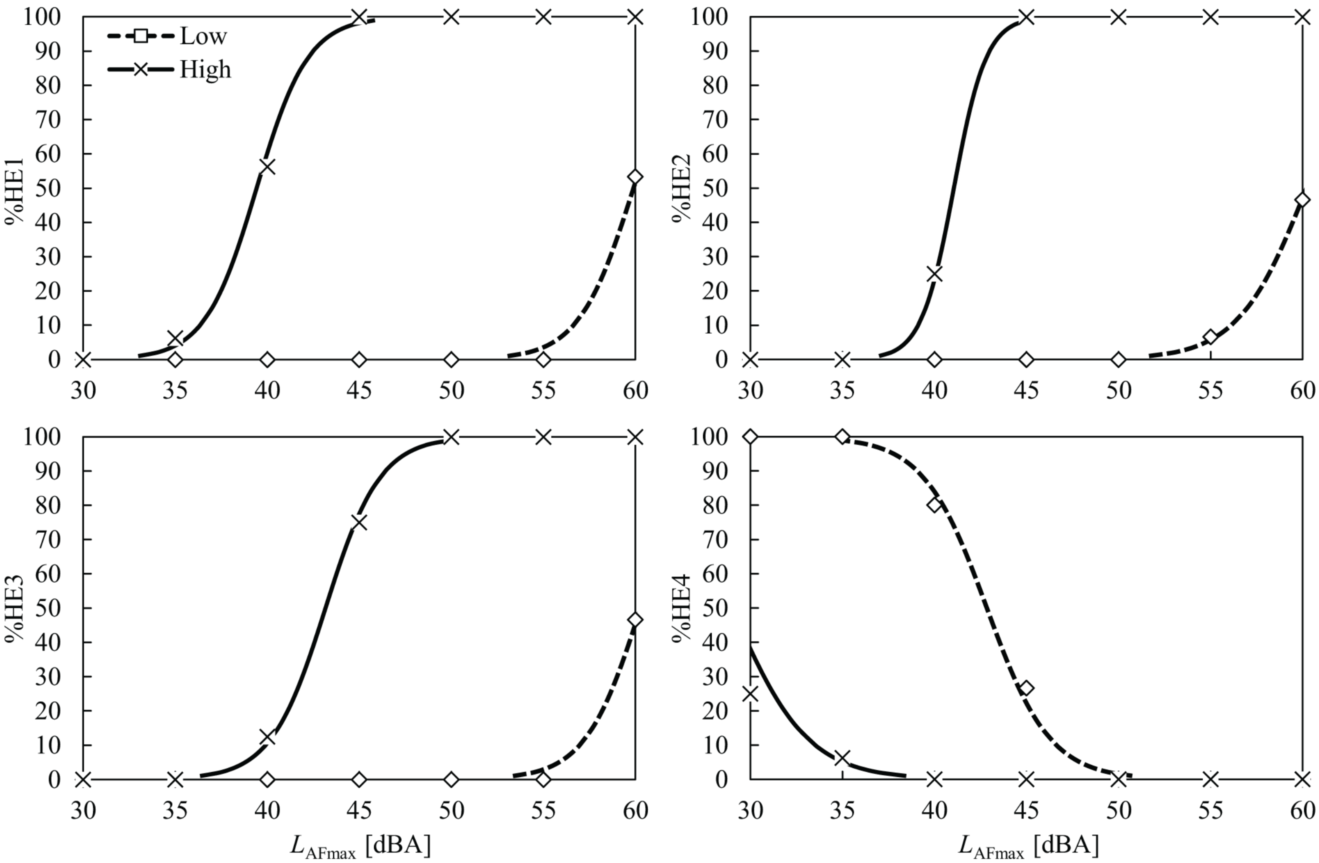


Fig 6. Percentage of high emotion ratings (%HE1–%HE4) for the low (□) and high (×) noise-sensitivity groups as a function of noise level. Probit regression curves are also presented for both groups.

https://doi.org/10.1371/journal.pone.0202058.g006

noise problem (e.g. by not apologising and continuing to make the noise). Noise-related crime among neighbours [31] could also be explained in relation to anger, which often motivates approach and attack behaviours [42].

The lexicons in the E2 cluster were related to the emotions of dislike and irritation, mostly towards the situation of noise exposure. Most lexicons in this cluster were closely related to the E1 cluster on anger. For instance, Shaver et al. [14] classified 'irritation' under a prototype of 'ANGER'. However, there are two significant differences between E1 and E2. Firstly, the lexicons in E1 expressed emotions mainly towards neighbours, whereas those in E2 tended to target the situation of noise exposure. Secondly, E1 and E2 had different levels of arousal according to the structure of emotion [10, 47, 48]. Most structures of emotion (e.g. Watson and Tellegen [47] and Larsen and Diener [48]) were developed based on the suggestion made by Russell [10], who proposed the structure of emotion using a circular model comprising two dimensions (appraisal dimensions of arousal and valence). According to the dimensional models, the lexicons in E1 and E2 had different levels of arousal; lexicons in E1 showed relatively high arousal, whereas those in E2 showed lower arousal. In this study, E2 also showed greater correlations with annoyance ratings compared with the other clusters, possibly due to the semantic similarity between the lexicon 'annoyance' and the lexicons in E2, such as 'bothered' or 'irritated'. Guski et al. [49] examined the concept of noise annoyance in different languages and listed ten expressions which were rated similarly to 'annoyance'. Most of them overlapped with the lexicons in E2, such as 'get on my nerves', 'irritated', and 'vexed'.

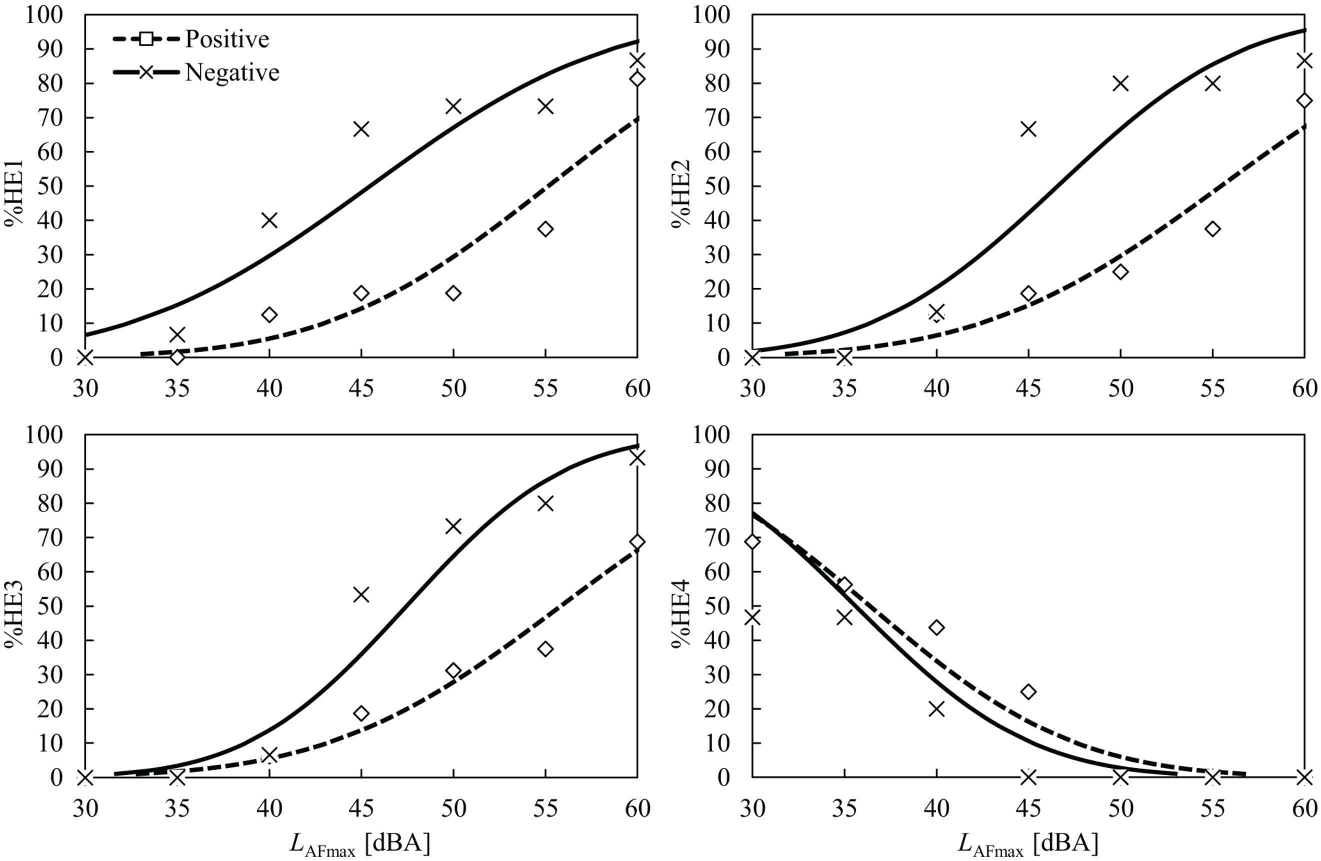


Fig 7. Percentage of high emotion ratings (%HE1–%HE4) for the positive (□) and negative (×) attitude groups as a function of noise level. Probit regression curves are also presented for both groups.

https://doi.org/10.1371/journal.pone.0202058.g007

The third cluster (E3) mainly contained lexicons representing physical and emotional pains. Shaver et al. [14] explored various lexicons expressing general emotions and grouped them into six groups including 'ANGER' and 'SADNESS'. In particular, 'SADNESS' included

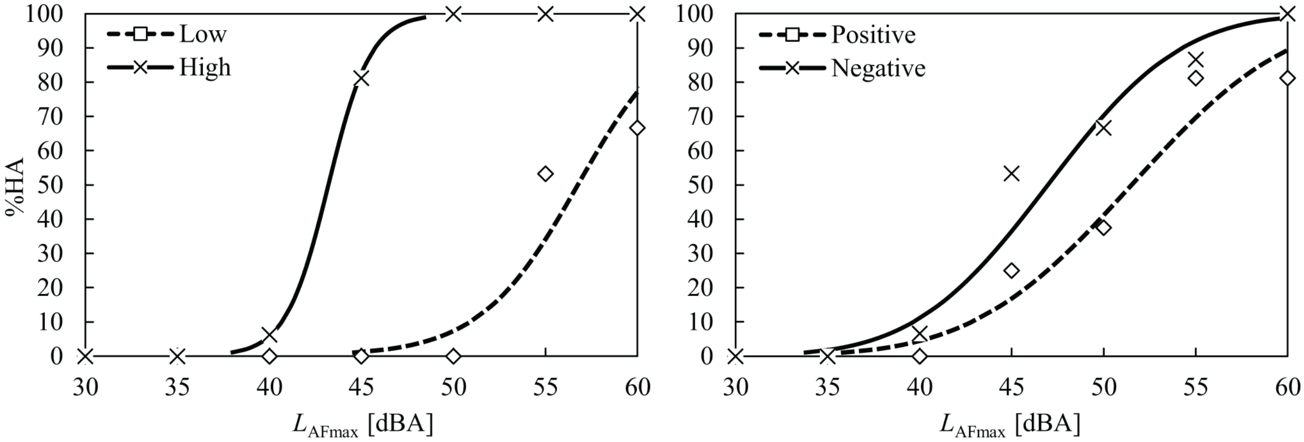


Fig 8. Percentage of highly annoyed (%HA) for the low (□) and high (×) noise-sensitivity groups and positive (□) and negative (×) attitude groups as a function of noise level. Probit regression curves are also presented for both groups.

https://doi.org/10.1371/journal.pone.0202058.g008

a subgroup expressing pain, such as 'suffering' and 'hurt'. However, in this study exploring the emotions evoked by a particular type of noise, pain was found to be one of the main emotion clusters. The emotion lexicons expressing sadness were initially included in the 120 collected lexicons, but they were not chosen often by the respondents in Survey I; consequently, they were not included in the 60 lexicons used in Survey II. This implies that the exposure to neighbours' footstep noise may not elicit the emotion of sadness to a considerable extent. In contrast to the emotions in E1 and E2 targeting the noise source and situation of noise exposure, respectively, the lexicons in E3 expressed the physical and emotional pain perceived by the respondents. For example, the lexicon 'vengeful' (E1) was directed towards the upstairs neighbours who were responsible for making the noise, and the lexicon 'unpleasant' (E2) was directed towards the situation that the respondent was exposed to the noise. On the other hand, 'feeling sick' (E3) was an expression that described what the respondent felt or perceive inwardly. These findings are in line with the results of a previous study suggesting that neighbour noise evokes outwardly directed aggression and inward reactions such as tension and feelings of pressure [17]. Given that many lexicons in E3 described physical pain (e.g. my head is throbbing, feeling sick, tired), this finding added further evidence to a previous finding that floor impact noise increases health complaints [25, 32].

The fourth cluster (E4) contained expressions narrated by residents who understood the situation of the noise event or their neighbours' circumstances of making noise, or by those who did not care much about the noise exposure. The lexicons in E4 expressed sympathy and empathy. According to Wispé [50], sympathy is a way of relating to others, which refers to an increased awareness of another person's plight as something to be alleviated, and therefore, it leads to an unselfish concern for the person. On the other hand, empathy is a way of knowing, which is an attempt of understanding the subjective experiences of another person without prejudice [50]. Some lexicons in E4 could be used to express sympathy. However, the other lexicons implied indifference or mere knowing and understanding, which comprise empathy [51, 52] rather than sympathy. Thus, the prototype E4 was labelled as 'EMPATHY'. In addition, empathy has been suggested to weaken annoyance as well as a vigilance coping strategy (e.g. making noise complaints) [32]. Thus, respondents who tended to exhibit higher ratings on the empathy-related cluster might have been likely to indicate having a lower level of annoyance. Moreover, it is unlikely for them to choose a vigilance coping strategy, as it may lead to conflicts with their neighbours [32]. This is in agreement with the findings of Zaki and Ochsner [53] who suggested that individuals often want to approach empathy when it facilitates important social goals, such as relationship formation and maintenance. Here, the relationship between neighbours can also be considered a variable that has a strong influence on empathy. Park et al. [32] proposed that the relationship with one's neighbours is an intervening condition that influences one's perception of noise events. It can be assumed that residents who have close and positive relationships with their neighbours may say 'there is no reason to get angry' (E4) regarding a noise event. In such situations, empathy develops through the positive relationship with one's neighbours. However, intervening conditions may decrease people's empathy when it is painful or costly, or when they interact with outgroup targets [53].

Intervening conditions

As mentioned earlier, intervening conditions cannot be overlooked when it comes to explaining emotions. Appraisals influence the emotions that are evoked [41], while other variables influence the procedure of appraisal. For example, residents who have a negative relationship with their neighbours may perceive less empathy and more negative emotions. The present study tested two intervening conditions which were suggested to have reciprocal relationships with the perception of and reaction to floor impact noise [32]: noise sensitivity and attitude towards neighbours. Guski [54] also emphasised that noise sensitivity, personal evaluations of the source, coping capacity, general attitude, history of noise exposure, and residents' expectations have important influences on noise annoyance. This study confirmed the findings of previous studies [24, 28, 32, 54], showing notably different trends between noise-sensitivity groups and attitude groups. Ryu and Jeon [24] highlighted a significant impact of noise sensitivity on the annoyance evoked by indoor residential noises. Park et al. [28] also found significant differences in the annoyance ratings for floor impact noise between low and high noise-sensitive participants via a laboratory experiment. Similarly, the present study found significant differences between the noise-sensitivity groups, which imply that higher noise sensitivity would influence individuals' appraisals to perceive higher anger, dislike, and pain, whereas low noise sensitivity may lead to a more empathetic appraisal of the event. This study also revealed that attitudes towards neighbours had an influential role in emotion and annoyance-evoking appraisals. Although there are clearer differences between the noise-sensitivity groups than the attitude groups presented in Figs 1 and 2, one cannot conclude that attitude did not have a significant role in emotional responses. Since Figs 1 and 2 illustrate the emotional changes in groups as the noise levels increased, it is reasonable to conclude that noise sensitivity was a grouping factor that reveals clear differences between the groups. Contrary to expectations, the attitude towards noise did not have a significant impact on emotions and noise annoyance. However, this could be further investigated by using more appropriate questions covering all different attitudes. The present study found that the participants with positive attitudes towards their upstairs neighbours provided lower negative emotion ratings (E1–E3), lower annoyance ratings, and higher empathy (E4). This result is consistent with the findings of Pedersen and Persson Waye [55], who revealed that the annoyance induced by wind turbine noise was affected by negative attitudes towards wind turbines.

Annoyance and emotions

Several studies have conducted questionnaire surveys and laboratory experiments to evaluate noise annoyance because it has been a most popular measure of the adverse effect of noise on individuals and on the community [21, 49, 54]. However, for neighbour noise, which frequently causes neighbour disputes including violence [30–32], it is appropriate to measure emotions evoked by neighbour noise because annoyance cannot adequately explain or predict potential disputes or relational problems between neighbours. Therefore, the measurement of emotions using lexicons targeting the noise source (i.e. E1) or the situation of noise exposure itself (i.e. E2) would be useful to determine the perceptual dimension of the respondents and to predict their future coping strategies. In practice, some of the clusters can be selected for the prompt measurement of emotional responses to noise. In particular, it would be quite useful to measure emotions using the E1 ('ANGER') and E4 ('EMPATHY') clusters rather than the E2 ('DISLIKE') and E3 ('PAIN') clusters, for the following reasons. First, given that emotion measurements aim to predict respondents' internal perceptions and future coping strategies, anger, an emotion which may develop into violent behaviours [42], needs to be measured, particularly in the case of noise issues between neighbours. Second, empathy needs to be assessed to predict future coping strategies. Empathy leads individuals to build or maintain positive relationships with others [53]. In particular, the present study found that empathy had the weakest correlation with annoyance. Since the measurement of annoyance cannot predict empathy, it needs to be assessed to yield extended insight into respondents' perception and to predict their future coping strategies. Third, E2 ('DISLIKE') can be excluded because it is strongly correlated with annoyance and because most of the lexicons in E2 were similar to annoyance [49]. Fourth, the lexicons in E3 ('PAIN') described pain, but as discussed earlier, some of them referred to health complaints [25, 32] and they may actually contain or be connected to some other emotions (e.g. anger and fear). Finally, correlations between E1, E2, and E3 and annoyance were consistently high (Table 8). However, Fisher's r to z transformation revealed that all the correlation coefficients were not statistically different [56]. This indicates the three emotion clusters ultimately measured the same construct (i.e. negative emotion), implying that the three clusters are interchangeable or that one cluster can cover most of what the other clusters would measure [57].

General discussion

Previously Namba et al. [18] used lexicons in an experiment to measure the impressions of sound stimuli. In particular, they collected a pool of Japanese adjectives from a preliminary experiment, but details about the experimental procedure (e.g. level of the stimuli) and main findings (e.g. the number of adjectives) were not explained. In contrast, the present study was designed carefully to collect appropriate lexicons. In this study, the lexicons were collected from two sources: (1) interview transcripts and (2) posts in online communities. The interview transcripts were chosen as a source because the interviews were conducted using grounded theory [32]. Based on the grounded theory methodology, the interviews were conducted until the researcher was confident that no more new findings could be obtained, so that theoretical saturation was attained [58]. Therefore, it was assumed that the interview transcripts included all the possible aspects of footstep noise and residents' reaction to the noise. The present study used a number of online posts from 18 online communities as another source of lexicons. From a number of online posts, only lexicons expressing emotions evoked by footstep noise were filtered and collected. Therefore, it can be said that the collected lexicons represent the narratives of residents adequately, particularly regarding footstep noise.

During the two online surveys, the respondents were asked to listen carefully to the noises via headphones. It was not possible to control the quality of sound reproduction, noise level, and background noise level. In particular, most headphones are limited to reproducing low-frequencies below 50 Hz. Thus, these practical constraints might have influenced the participants' responses and the selection of the lexicons. However, all participants had experienced footstep noise from their upstairs neighbours. Therefore, they were expected to rate the lexicons based on their previous experiences and their experiences with hearing the noises via headphones. Nonetheless, the sound reproduction system (loudspeaker and subwoofer) used in the laboratory experiment is considered to be more useful to evoke people's emotions related to footstep noise, including low-frequency components. Therefore, in the future, a small-scale study could be conducted to validate the selection of lexicons in the laboratory.

Based on the present findings, the following recommendations for future research are made. First, it would be useful to examine the emotions evoked by different types of noises. For instance, neighbour noise comprises several other noise sources. Emotions evoked by other types of floor impact noise (e.g. chair/furniture scraping) or airborne noises (e.g. voice/conversations of neighbours) can also be examined to identify any influences of different noise sources. It can also be assumed that different floor materials, shoe types, and body sizes would induce different footstep noises [59]; thus, different footstep noise stimuli may also evoke different emotional responses as well. Moreover, the concept of total annoyance can be utilised in future neighbour noise studies. It is known that the annoyance response to a single noise source and the total annoyance evoked by combined noises differ [60, 61]. Similarly, it is expected that the annoyance and emotional responses evoked by a general term of floor impact noise or neighbour noise would be different from those evoked by different single sources (e.g. footsteps, dropping of items). For example, it can be assumed that a general floor impact noise (i.e. combined) would elicit higher anger and annoyance than exposure to footstep noise alone. Second, there are several emotion lexicons in different languages and they contain different nuances of emotions. Moreover, cultural differences in emotion will yield further insights [62, 63]. Given that neighbour noise is not a problem in Korea alone, emotion research using lexicons in different languages and cultures would yield further insight into emotional responses to this type of noise. Third, different attempts could be made to evoke emotions. Participants are highly likely to become passive observers if they receive one-way, simplified, and well-controlled stimuli [64], as human emotions naturally occur in interaction with others and external events [65]. As this study presented stimuli and did not ask participants to engage or interact with anything, the participants might have responded to the questionnaire as passive observers. Thus, it is difficult to define to which extent emotions resulted from stimuli, and this study may have missed some important emotional processing factors [64]. Further consideration of methods for evoking emotional responses to neighbour's noise in a more engaging and ecological way could be examined in the future [66]. Fourth, different methods could be used to measure emotions. Emotion lexicons are linguistic expressions, so there is a possibility that they could be either understated or overstated by the respondents. Moreover, emotion lexicons may not fully reflect the perceivers' true emotional status, especially if they are not aware of their real inward feelings. Thus, a questionnaire survey can be provided along with measurements of physiological responses because brain and bodily functions are strongly synchronised by emotion-evoking stimuli [64]. In addition, assessments in performance settings may be of use to understand the subjective states of participants affected by noise through pre/post-test assessments. Questionnaire scales have been commonly used to assess subjective responses, but this type of scale primarily measures conscious feeling states, which only represent a partial expression of some underlying emotional process [67]. One important advantage of a performance setting is that demanding tasks elicit various stress responses, such as anxiety and worry, which facilitates an examination of subjective states [67]. Therefore, future research could be carried out in performance settings and could assess subjective states before and after eliciting emotional experiences through noise.

Conclusion

In the present study, lexicons expressing emotions induced by neighbours' footstep noise were collected and emotional responses were assessed in a large sample of participants hearing noises. Throughout the study, noise stimuli were used to simulate neighbours' footstep noise particularly that made by a child and an adult. First, a total of 120 Korean lexicons were chosen from interview transcripts and online community posts. The number of lexicons was reduced to 60 through an online survey. Participants in the first survey were residents of multi-family housing buildings ($n = 133$) and they were asked to choose appropriate lexicons expressing their emotions while listening to the noises. Subsequently, another online survey was conducted with 89 residents, who rated the appropriateness of each lexicon while hearing the noises. Based on their responses, the lexicons were classified into four clusters. Negative emotions related to anger, dislike, and pain were grouped in three different clusters (E1–E3), while lexicons expressing empathy were grouped in E4. In the laboratory experiment, twenty lexicons were presented to the participants ($n = 41$), and they were asked to rate each lexicon based on their feelings during noise exposure. Noise stimuli were presented at noise levels between 30 and 60 dBA (L_{AFmax}), in 5 dB intervals. It was found that the emotion and noise annoyance were significantly affected by noise levels, indicating that greater noise levels led to greater negative emotions and annoyance ratings. Because exposure to noise causes negative reactions such as annoyance, the three clusters representing negative emotions were strongly correlated with noise annoyance. The emotion cluster expressing 'DISLIKE'

(E2) showed the strongest correlation with noise annoyance, whereas that expressing 'EMPATHY' (E4) showed the weakest correlation with noise annoyance. This study also tested whether noise sensitivity and attitudes were moderators influencing emotional responses and annoyance ratings. Both noise sensitivity and attitudes were found to significantly affect emotional responses. In particular, it was revealed that there were clear gaps between the low and high noise-sensitivity groups' level of emotions and annoyance. Overall, the present findings suggest that lower noise level, lower noise sensitivity, and more positive attitudes towards neighbours would evoke less negative emotions and annoyance when neighbours' footstep noises are heard. This study provides evidence that can be used in dealing with neighbour disputes and in preventing such problems in advance. Noise levels can be reduced by helping residents become aware of which activities make loud noises (e.g. children's jumping and running [68]) and when people tend to perceive these noise events as louder. For instance, people tend to complain more about noise exposure at night or early in the morning when ambient noise levels are relatively low [32]. The findings of this study could also be used by the management office, mediation services, and local authorities. Once they address the dispute, the residents' emotions evoked by floor impact noise could be assessed with noise sensitivity and attitude measurements with respect to the noise source. They can then interpret the severity of the negative perception and could estimate noise exposure levels based on the relationship between the noise level and emotions. An understanding of the emotional status of residents and its relation to noise levels could be useful for solving disputes between neighbours.

Supporting information

S1 Table. Keywords used for searching online postings.
(DOCX)

S1 File. Questions used in the laboratory experiment.
(DOCX)

S2 File. Responses collected from the laboratory experiment.
(XLSX)

Author Contributions

Conceptualization: Sang Hee Park, Pyoung Jik Lee.

Data curation: Sang Hee Park, Jeong Ho Jeong.

Formal analysis: Sang Hee Park.

Funding acquisition: Pyoung Jik Lee.

Investigation: Sang Hee Park, Pyoung Jik Lee.

Methodology: Sang Hee Park, Pyoung Jik Lee.

Project administration: Pyoung Jik Lee.

Resources: Pyoung Jik Lee, Jeong Ho Jeong.

Software: Jeong Ho Jeong.

Supervision: Pyoung Jik Lee.

Visualization: Sang Hee Park.

Writing – original draft: Sang Hee Park.

Writing – review & editing: Pyoung Jik Lee.

References

1. Morgan CT, King RA, Robinson NM. Introduction to psychology. 6 ed. New York: McGraw-Hill; 1979.
2. Ekman P, editor Universals and cultural differences in facial expressions of emotion. Nebraska Symposium on Motivation; 1971: University of Nebraska Press.
3. Davidson RJ, Ekman P, Saron CD, Senulis JA, Friesen WV. Approach-withdrawal and cerebral asymmetry: Emotional expression and brain physiology: I. Journal of Personality and Social Psychology. 1990; 58(2):330–41. PMID: 2319445
4. Öhman A, Flykt A, Esteves F. Emotion drives attention: detecting the snake in the grass. Journal of Experimental Psychology: General. 2001; 130(3):466–78.
5. Tajadura-Jiménez A, Väljamäe A, Asutay E, Västfjäll D. Embodied auditory perception: The emotional impact of approaching and receding sound sources. Emotion. 2010; 10(2):216–29. https://doi.org/10.1037/a0018422 PMID: 20364898
6. Tajadura-Jiménez A, Larsson P, Väljamäe A, Västfjäll D, Kleiner M. When room size matters: acoustic influences on emotional responses to sounds. Emotion. 2010; 10(3):416–22. https://doi.org/10.1037/a0018423 PMID: 20515229
7. Öhman A, Soares JJ. "Unconscious anxiety": Phobic responses to masked stimuli. Journal of Abnormal Psychology. 1994; 103(2):231–40. PMID: 8040492
8. Matsumoto D, Keltner D, Shiota MN, O'Sullivan M, Frank M. Facial expressions of emotion. In: Lewis M, Haviland-Jones JM, Feldman Barrett L, editors. Handbook of Emotions. 3 ed. NY: The Guilford Press; 2008. p. 211–34.
9. Cacioppo JT, Berntson GG, Larsen JT, Poehlmann KM, Ito TA. The psychophysiology of emotion. Handbook of Emotions. 2000; 2:173–91.
10. Russell JA. A circumplex model of affect. Journal of Personality and Social Psychology. 1980; 39:1161–78.
11. Fehr B, Russell JA. Concept of emotion viewed from a prototype perspective. Journal of Experimental Psychology: General. 1984; 113(3):464–86.
12. Ortony A, Clore GL, Foss MA. The referential structure of the affective lexicon. Cognitive Science. 1987; 11(3):341–64.
13. Clore GL, Ortony A, Foss MA. The psychological foundations of the affective lexicon. Journal of Personality and Social Psychology. 1987; 53(4):751–66.
14. Shaver P, Schwartz J, Kirson D, O'connor C. Emotion knowledge: Further exploration of a prototype approach. Journal of Personality and Social Psychology. 1987; 52(6):1061–86. PMID: 3598857
15. Bentley M. Is "emotion" more than a chapter heading? In: L RM, editor. Feelings and Emotions: The Wittenberg Symposium. Worcester, Massachusetts: Clark University Press; 1928.
16. Greenwald MK, Cook EW, Lang PJ. Affective judgment and psychophysiological response: Dimensional covariation in the evaluation of pictorial stimuli. Journal of Psychophysiology. 1989; 3(1):51–64.
17. Grimwood C. Effects on environmental noise on people at home. Information Paper 22/93. UK: BRE; 1993.
18. Namba S, Kuwano S, Hashimoto T, Berglund B, Da Rui Z, Schick A, et al. Verbal expression of emotional impression of sound. Journal of the Acoustical Society of Japan. 1991; 12(1):19–29.
19. Gomez P, Danuser B. Affective and physiological responses to environmental noises and music. International Journal of Psychophysiology. 2004; 53(2):91–103. https://doi.org/10.1016/j.ijpsycho.2004.02.002 PMID: 15210287
20. Hume K, Ahtamad M. Physiological responses to and subjective estimates of soundscape elements. Appl Acoust. 2013; 74(2):275–81.
21. Stansfeld S, Haines M, Brown B. Noise and health in the urban environment. Reviews on Environmental Health. 2000; 15(1–2):43–82. PMID: 10939085
22. Bronzaft AL. Noise pollution: A hazard to physical and mental well-being. In: Bechtel RB, Churchman A, editors. Handbook of Environmental Psychology: John Wiley & Sons, Inc.; 2002. p. 499–510.
23. Raw G, Oseland N. Subjective response to noise through party floors in conversion flats. Appl Acoust. 1991; 32(3):215–31.
24. Ryu JK, Jeon JY. Influence of noise sensitivity on annoyance of indoor and outdoor noises in residential buildings. Appl Acoust. 2011; 72(6):336–40.
25. Park SH, Lee PJ, Yang KS, Kim KW. Relationships between non-acoustic factors and subjective reactions to floor impact noise in apartment buildings. J Acoust Soc Am. 2016; 139(3):1158–67. https://doi.org/10.1121/1.4944034 PMID: 27036252

26. Guite H, Clark C, Ackrill G. The impact of the physical and urban environment on mental well-being. Public Health. 2006; 120(12):1117–26. https://doi.org/10.1016/j.puhe.2006.10.005 PMID: 17097120
27. Maschke C, Niemann H. Health effects of annoyance induced by neighbour noise. Noise Control Eng J. 2007; 55(3):348–56.
28. Park SH, Lee PJ, Jeong JH. Effects of noise sensitivity on psychophysiological responses to building noise. Build Environ. 2018; 136:302–11.
29. Park SH, Lee PJ. Effects of floor impact noise on psychophysiological responses. Build Environ. 2017; 116:173–81.
30. Stokoe E, Hepburn A. 'You can hear a lot through the walls': Noise formulations in neighbour complaints. Discourse & Society. 2005; 16(5):647–73.
31. Park KH. Criminal study on the noise—Focused on the floor impact noise dispute (in Korean). Inha Law Review. 2015; 18:297–328.
32. Park SH, Lee PJ, Yang KS. Perception and reaction to floor impact noise in apartment buildings: a qualitative approach. Acta Acust United Ac. 2016; 102(5):902–11.
33. Ahn SH, Lee SH, Kwon OS. Activation dimension: A mirage in the affective space? (in Korean). Korean Journal of Social and Personality Psychology. 1993; 7(1):107–23.
34. Hahn DW, Kang HJ. Appropriateness and frequency of emotion terms in Korea. The Korean Journal of Psychology. 2000; 19(2):63–99.
35. Park IJ, Min KH. Making a list of Korean emotion terms and exploring dimensions underlying them (in Korean). Korean Journal of Social and Personality Psychology. 2005; 19:109–29.
36. Sohn SJ, Park MS, Park JE, Sohn JH. Korean emotion vocabulary: Extraction and categorization of feeling words (in Korean). Science of Emotion adn Sensibility. 2012; 15(1):105–20.
37. Faul F, Erdfelder E, Lang A-G, Buchner A. G* Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. Behavior Research Methods. 2007; 39(2):175–91. PMID: 17695343
38. Faul F, Erdfelder E, Buchner A, Lang A-G. Statistical power analyses using G* Power 3.1: Tests for correlation and regression analyses. Behavior Research Methods. 2009; 41(4):1149–60. https://doi.org/10.3758/BRM.41.4.1149 PMID: 19897823
39. Weinstein ND. Individual differences in reactions to noise: a longitudinal study in a college dormitory. Journal of Applied Psychology. 1978; 63(4):458–66. PMID: 701213
40. Schultz TJ. Synthesis of social surveys on noise annoyance. J Acoust Soc Am. 1978; 64(2):377–405. PMID: 361792
41. Roseman IJ, Spindel MS, Jose PE. Appraisals of emotion-eliciting events: Testing a theory of discrete emotions. Journal of Personality and Social Psychology. 1990; 59(5):899–915.
42. Harmon-Jones E, Harmon-Jones C. Anger. In: Feldman Barrett L, Lewis M, Haviland-Jones JM, editors. Handbook of Emotions. 4 ed. NY: Guilford Press; 2016. p. 774–91.
43. Lewis M. The development of anger and rage. Rage, Power, and Aggression. 1993:148–68.
44. Roseman IJ. Appraisal determinants of discrete emotions. Cognition and Emotion. 1991; 5(3):161–200.
45. Lazarus RS. Emotion and adaptation: Oxford University Press on Demand; 1991.
46. Scherer KR. Appraisal considered as a process of multilevel sequential checking. In: Scherer KR, Schorr A, Johnstone T, editors. Appraisal Processes in Emotion: Theory, Methods, Research. New York: Oxford University Press; 2001. p. 92–120.
47. Watson D, Tellegen A. Toward a consensual structure of mood. Psychological bulletin. 1985; 98 (2):219–35. PMID: 3901060
48. Larsen RJ, Diener E. Promises and problems with the circumplex model of emotion. In: S. CM, editor. Review of Personality and Social Psychology, No 13 Emotion. Thousand Oaks, CA: Sage Publications, Inc.; 1992. p. 25–59.
49. Guski R, Felscher-Suhr U, Schuemer R. The concept of noise annoyance: How international experts see it. J Sound Vib. 1999; 223(4):513–27.
50. Wispé L. The distinction between sympathy and empathy: To call forth a concept, a word is needed. Journal of Personality and Social Psychology. 1986; 50(2):314–21.
51. Darwall S. Empathy, sympathy, care. Philosophical Studies. 1998; 89(2–3):261–82.
52. Keen S. A theory of narrative empathy. Narrative. 2006; 14(3):207–36.
53. Zaki J, Ochsner K. Empathy. In: Feldman Barrett L, Lewis M, Haviland-Jones JM, editors. Handbook of Emotions. 4 ed. NY: Guilford Press; 2016. p. 871–84.

54. Guski R. Personal and social variables as co-determinants of noise annoyance. Noise Health. 1999; 1 (3):45–56. PMID: 12689499

55. Pedersen E, Persson Waye K. Wind turbine noise, annoyance and self-reported health and well-being in different living environments. Occup Environ Med. 2007; 64(7):480–6. https://doi.org/10.1136/oem.2006.031039 PMID: 17332136

56. Steiger JH. Tests for comparing elements of a correlation matrix. Psychological bulletin. 1980; 87 (2):245–51.

57. Steinborn MB, Langner R, Flehmig HC, Huestegge L. Methodology of performance scoring in the d2 sustained-attention test: cumulative-reliability functions and practical guidelines. Psychological Assessment. 2018; 30(3):339–57. https://doi.org/10.1037/pas0000482 PMID: 28406669

58. Corbin JM, Strauss A. Basics of qualitative research: Techniques and procedures for developing grounded theory. 3 ed. Thousand Oaks, CA: SAGE; 2008.

59. Turchet L, Moffat D, Tajadura-Jiménez A, Reiss JD, Stockman T. What do your footsteps sound like? An investigation on interactive footstep sounds adjustment. Appl Acoust. 2016; 111:77–85.

60. Öhrström E, Barregård L, Andersson E, Skånberg A, Svensson H, Ängerheim P. Annoyance due to single and combined sound exposure from railway and road traffic. J Acoust Soc Am. 2007; 122(5):2642–52. https://doi.org/10.1121/1.2785809 PMID: 18189556

61. Jeon JY, Lee PJ, You J, Kang J. Perceptual assessment of quality of urban soundscapes with combined noise sources and water sounds. J Acoust Soc Am. 2010; 127(3):1357–66. https://doi.org/10.1121/1.3298437 PMID: 20329835

62. Watson D, Clark LA, Tellegen A. Cross-cultural convergence in the structure of mood: A Japanese replication and a comparison with US findings. Journal of Personality and Social Psychology. 1984; 47 (1):127–44.

63. Grossmann I, Ellsworth PC, Hong Y-y. Culture, attention, and emotion. Journal of Experimental Psychology: General. 2012; 141(1):31–6.

64. Hari R, Henriksson L, Malinen S, Parkkonen L. Centrality of social interaction in human brain function. Neuron. 2015; 88(1):181–93. https://doi.org/10.1016/j.neuron.2015.09.022 PMID: 26447580

65. Gilam G, Hendler T. With love, from me to you: embedding social interactions in affective neuroscience. Neuroscience & Biobehavioral Reviews. 2016; 68:590–601.

66. Schmidt B, Warns L, Hellmer M, Ulrich N, Hewig J. What Makes Us Feel Good or Bad. Journal of Individual Differences. 2018; 39:142–50.

67. Matthews G, Campbell SE, Falconer S, Joyner LA, Huggins J, Gilliland K, et al. Fundamental dimensions of subjective state in performance settings: Task engagement, distress, and worry. Emotion. 2002; 2(4):315–40. PMID: 12899368

68. Park SH, Lee PJ, Lee BK. Levels and sources of neighbour noise in heavyweight residential buildings in Korea. Appl Acoust. 2017; 120:148–57.

Accepted for publication
In: Applied Acoustics, 150, 268-278. (doi: 10.1016/j.apacoust.2019.02.021)

Reaction to floor impact noise in multi-storey residential buildings: The effects of acoustic and non-acoustic factors

Sang Hee Park and Pyoung Jik Lee

Acoustics Research Unit, School of Architecture, University of Liverpool, Liverpool, UK

Running title: Reaction to floor impact noise

Corresponding author:

Pyoung Jik Lee, Acoustics Research Unit, School of Architecture, University of Liverpool, Liverpool, L69 7ZN, UK.

Email: P.J.Lee@liverpool.ac.uk

Abstract

This study aimed to investigate whether different acoustic and non-acoustic factors have effects on the subjective responses to floor impact noise made by upstairs neighbours in multi-story residential buildings. An on-site evaluation was conducted in four different apartment complexes with 100 residents from each site ($N = 400$). All the buildings had a box-frame-type structure with reinforced concrete slab floors with different thicknesses; two sites used 150 mm slabs, another used 180 mm, and the last used 210 mm slabs. The participants responded to a questionnaire which measured annoyance, anger, and empathy as their subjective responses to floor impact noise. The questionnaire also asked about socio-demographic, personal, and situational variables. Outdoor noise measurements were carried out for 24 hours on the top of the buildings at each site in order to assess any masking effect of ambient noise on the subjective responses to the indoor noise. Results showed that the subjective responses were significantly affected by noise sensitivity and house ownership. Those who had higher noise sensitivity or those who were house owners reported higher annoyance and anger towards floor impact noise. Outdoor noise did not have any masking effect on the responses but those who lived in higher ambient noise levels reported higher annoyance and anger to the indoor noise. The subjective responses were not solely understood by slab thickness; however, slab thickness contributed to predicting the subjective responses with other variables. These findings imply that it is limited to fully explain the subjective responses to floor impact noise without other acoustic and non-acoustic factors such as noise sensitivity.

1 Introduction

Residents in multi-story residential buildings are easily exposed to floor impact noise coming from upstairs. In particular, floor impact noise has been suggested as the most annoying noise source in this type of housing in South Korea [1-3]. Statistics Korea [4] reported that such type of housing accounted for over 60.1% of the whole housing units available in 2016. It means that there is a large segment of the population in South Korea who are likely to be exposed to floor impact noise. The proportion of multi-story residential buildings has been growing all over the world [5, 6]. According to the recent report of the Floor Noise Management Centre in Korea, there were 123,969 complaints about both structure-borne and air-borne noise from neighbours since 2012 [7]. In addition, 82.6% of the complaints were due to floor impact noise, which includes 70.9% of footstep noise [7]. This report supports the previous findings that footstep noise such as walking, running, and jumping evoked the most annoyance to the residents [1, 3]. The report also stated that the majority of noise complainants resulted in disputes and conflicts with their neighbours [7]. Furthermore, four murder cases between neighbours were recorded in 2013 which were retaliatory crimes caused by an emotional reaction to noise issues [8].

A number of studies have attempted to investigate the subjective responses to floor impact noise in laboratory settings. They have found that higher A-weighted maximum sound pressure levels (L_{Amax}) led to greater self-reported annoyance responses [9, 10]. Lee et al. [9] examined the subjective responses to noise stimuli induced by an impact ball and found that sound quality ratings (e.g. Zwicker's Loudness Level, LL_{Z}) and instrumental metrics (e.g. L_{Amax}) had significant correlations with self-reported annoyance ratings. In particular, L_{Amax} was suggested as a practical descriptor of the auditory sensation of the impact ball noise [9]. Recent studies also supported the strong relationship between the L_{Amax} of impact sounds and self-reported annoyance [11, 12]. In addition, exposure to floor impact noise has been found to influence physiological changes such as heart rate and respiration rate [13, 14].

Accordingly, there have been a lot of attempts to reduce floor impact noise levels by developing acoustic materials and floor structures. For instance, floating floors have been widely used to decrease structure-borne and air-borne sound transmission by isolating the upper parts of the floors from the structure [15]. Although floating floors were effective at reducing lightweight impact noise, little change was found in relation to heavyweight impact noise levels [16]. Another way to reduce both heavyweight and lightweight noise levels is to increase slab thickness. There are previous studies which have reported the notable relationship between slab thickness and floor impact noise levels [17-19]. More precisely, heavyweight impact sound pressure levels decreased by 2 dB when the slab thickness increased by 30 mm [19]. A more recent study found that 20 mm increments in concrete slab thickness led to a decrease in impact sound pressure levels between 3 and 7 dB [17]. Yeon et al. [20] measured sound pressure levels of standard and real impact sounds in 30 apartments with different slab thicknesses (i.e. 135, 150, 180, and 210 mm). They confirmed the previous suggestions by providing significant negative correlations between slab thickness and sound pressure levels [20]. In particular, slab thickness had the biggest negative correlation with impact noise levels of a tapping machine while it showed the smallest correlation with noise levels of real impact sources such as an adult’s walking [20]. Based on such research findings, the Korean Government has strengthened domestic regulations since 2005 by increasing the concrete slab thicknesses to 210 mm [21, 22]. Therefore, it was expected that the increase in slab thickness would resolve the noise complaints due to floor impact noise in recently built apartments.

On the other hand, data from a recent field measurement are rather controversial because it showed there was no general relationship between slab thickness and floor impact noise levels [23]. Park et al. [23] conducted noise measurements for 24 hours in 26 residential buildings while the occupants vacated their houses. The sites were classified into two groups based on the slab thickness: the first group were those with slab thicknesses of 135 and 150 mm and the second group were those with slab thicknesses of 180 and 210 mm. It was found that the L_{Amax} of the first group was slightly higher than that of the second group, but the difference was not statistically significant. However, Park et al. [23] did not assess the subjective responses to floor impact noise; therefore, it is necessary to investigate the relationship between slab thickness and the subjective responses to the noise. Emotional responses (e.g. anger) to the noise would be worth being assessed because annoyance cannot be fully predicted by noise level itself [24] and in order to test a previous suggestion of the correlations between annoyance and different emotions [25].

This study, therefore, sets out to assess the effect of slab thickness on the subjective responses to floor impact noise by conducting questionnaire surveys. It was hypothesised that thicker slabs would lead to less negative reactions to floor impact noise. It was also hypothesised that there would be acoustic and non-acoustic factors affecting the perception of floor impact noise. In order to validate this hypothesis, several non-acoustic factors were introduced such as noise sensitivity and house ownership. Field surveys were performed in four apartment complexes which used different slab thicknesses. Participants were asked to rate their annoyance, anger, and empathy as to the floor impact noise heard in their homes. In addition, it was assessed if the subjective responses were affected by socio-demographic, personal, and situational variables. During the surveys, outdoor noise levels were measured to test if ambient noise masks the subjective responses to floor impact noise [26].

2 Methods

2.1 Sites

As listed in Table 1, four apartment complexes in the Gyeonggi province of South Korea took part in the study. The oldest one was built in 1994 (Site A) and the newest site was built in 2014 (Site D). The biggest site had 1,827 houses (Site A), whereas the smallest one had 262 houses (Site C). Slab thickness of the apartments varied from 150 to 210 mm: 150 mm slabs were used in Sites A and B, 180 mm in Site D, and 210 mm in Site C. Floor area also varied from 52 (in Site D) to 157 m^2 (in Site C). The average price per square metre of residences in Site A was the highest but the properties at Site C were the most expensive due to the bigger floor area. Site D was a type of public rental housing which is owned by the government and offered with a long-term rent plan. Thus, there was no information about the average price per square metre for Site D. The present study aimed to minimise the variations of factors affecting floor impact noise levels. First, all the buildings had the same structure which is a box-frame-type reinforced concrete construction. Secondly, the buildings with similar floor structures were chosen. As shown in Figure 1, the floors consisted of the reinforced concrete slab, resilient material, lightweight concrete, and finishing mortar. All the resilient materials were Expanded Polystyrene (EPS) and thicknesses of the materials varied from 20 to 30 mm.

Table 1

Figure 1

As shown in Figure 2, there were traffic roads near all of the sites. Sites A and B were nearby roads with three or more lanes, while Sites C and D were close to roads with a smaller number of (e.g. one or two) lanes. In addition, Sites A, B, and C were located in the vicinity of railways so they were exposed to additional railway noise. Outdoor noise levels were measured for 24 hours using sound level metres (SVAN 943, Svantek) positioned 1.2 m above the ground mounted on tripods. All sound level metres were placed on top of the buildings which are marked in grey in Figure 2. Outdoor noise levels of Site C could only be measured at three buildings due to the apartment complex's regulations. At the other sites, outdoor noise levels were measured at five buildings each. From the 24-hour noise recordings, L_{DEN} (Day-Evening-Night noise levels) were calculated. A penalty of 5 dB was added from 19:00 to 22:00, and a penalty of 10 dB was added from 22:00 to 07:00 to derive L_{DEN}.

Figure 2

2.2 Questionnaire

Participants were asked to complete the questionnaire during face-to-face interviews in separated rooms within the management office of each site. In the present study, the questionnaire was divided into three main sections. The first section dealt with the participants' responses to floor impact noise in their homes. First, the level of annoyance caused by floor impact noise was assessed. Noise annoyance was rated using an 11-point scale (0 = *'not at all'* and 10 = *'extremely'*) as recommended by the ICBEN team [27] and the ISO 15666 standard [28]. Participants were provided with the following instruction: "Thinking about the last 12 months or so, when you are in your home, how much does floor impact noise annoy you?" Second, the emotional responses to floor impact noise, particularly anger and empathy, were assessed using 10 lexicons provided in the recent study [25]. The five lexicons used for anger were 'unhappy', 'detestable', 'can't understand', 'get enraged', and 'ridiculous', while the five lexicons about empathy were 'bearable', 'just being patient', 'tolerable', 'no reason for discomfort', and 'think of it as usual'. The participants were asked to rate their emotions on a 7-point scale (0 = *'not at all'* and 6 = *'extremely'*) according to the following instruction: "Please rate the extent to which each lexicon is appropriate for expressing your emotions towards the floor impact noise you have heard for the last 12 months." For those who had lived in their current houses for less than 12 months, they were asked to think about the period that they had lived in the current house. The second section of the questionnaire was to measure situational variables [29] in terms of the major noise source, time of the noise exposure, and any child(ren) upstairs; these were regarded as acoustic factors because they were the details of the floor impact noise which the participants had been mainly exposed to. The participants were asked to choose one of six noise sources; the six sources were adopted from the previous report on the most common noise sources in real apartment buildings [23]. They were two heavyweight impact noise sources (i.e. children's footsteps and adults' footsteps) and four lightweight impact noise sources (i.e. furniture scraping, items dropping, door banging, and plumbing system). Five options were given for the participants to choose the major time of the noise exposure: 06:00 ~ 09:00, 09:00 ~ 12:00, 12:00 ~ 18:00, 18:00 ~ 20:00, and 20:00 ~ 06:00. The questionnaire also asked whether there were any children living upstairs since the footstep noise of children has been known to be the dominant noise source in apartment buildings [15]. The third section of the questionnaire concerned non-acoustical factors affecting the subjective responses to noise. Non-acoustical factors were classified into personal and socio-demographic variables [29]. As a personal variable, noise sensitivity was measured using Weinstein's scale [30].

2.3 Participants

One hundred residents from each site took part in the study. Information about the participants is listed in Table 2. The age of the participants ranged from 20 to 60 years old and the mean age of the whole participants was 42.9 years old (std. deviation = 10.5). Male and female participants were recruited almost evenly from each site. More than half of the participants from Sites A and C reported that they did not live with a child. More than half of participants from Sites B and C reported that there were one or more children living upstairs. Most of the participants' education levels were at university/college level. The majority of the participants were employed and most of them were employed full-time. Length of residency ranged from 2 months to 277 months (23 years and 1 month), partially correlating with the age of the building. Most of the participants from Sites A, B, and C reported that they owned their houses, whereas all of the participants from Site D rented their houses from the government.

Table 2

2.4 Data analysis

Statistical analyses were conducted using SPSS for Windows (version 22.0, SPSS Inc. Chicago, IL). Bivariate correlations were tested in order to examine correlations between the variables. The significance of differences between two correlation coefficients was tested using Fisher's r-to-z transformation (an online computation available at http://vassarstats.net/index.html). In the case of two correlation coefficients obtained from the same sample which shared one variable in common, each correlation coefficient was converted into z-score using Fisher's r-to-z transformation and the asymptotic covariance of the estimates was calculated by Steiger's equations [31]. Independent samples *t*-tests and one-way analyses of variance (one-way ANOVA) were performed to compare the responses between groups. In addition, multiple linear regression analyses were conducted to investigate significant variables influencing the responses. In the present study, p values of less than 5% ($p < 0.05$) were considered as statistically significant.

3 Results

Figure 3 illustrates the subjective responses (i.e. annoyance, anger, and empathy) to floor impact noise across the four sites. The annoyance rating of Site A was the highest (mean = 4.5; std. deviation = 3.4), whereas Site D showed the lowest rating (mean = 3.4; std. deviation = 2.6). Only the annoyance ratings between Sites A and D were significantly different ($p < 0.05$), indicating that the residents of Site A experienced a greater level of noise annoyance due to floor impact noise than those in Site D. Similarly, Site A and Site D showed the highest (mean = 2.6; std. deviation = 1.3) and lowest (mean = 1.7; std. deviation = 1.1) anger ratings respectively and they were significantly different ($p < 0.01$). Significant differences were also found between Sites A and B, as well as Sites C and D ($p < 0.01$ for both). In empathy ratings, the rating of Site B was the highest, followed by Sites D, A, and C. It was found that most of the empathy ratings were significantly different from one another ($p < 0.01$ for all).

Figure 3

3.1 The effects of acoustic factors

The annoyance, anger, and empathy ratings caused by floor impact noise across different slab thicknesses (i.e. 150, 180, and 210 mm) are plotted in Figure 4. Sites A and B used the same slab thickness (i.e. 150 mm) so the results of the two sites were merged together for this comparison. The highest annoyance rating was observed from the 150 mm slabs (mean = 4.3; std. deviation = 3.0). However, contrary to expectations, the annoyance rating of the 180 mm slabs was lower than the 210 mm slabs. In addition, the annoyance ratings of different slab thicknesses were not statistically different. It was hypothesised that the residents living in buildings with thicker slabs would report lower anger and higher empathy than others with thinner slabs. However, the lowest anger (mean = 1.7; std. deviation = 1.1) and the highest empathy (mean = 3.6; std. deviation = 0.7) were found in the 180 mm slabs (i.e. Site D). The participants from the site with 210 mm slabs (i.e. Site C) even reported the highest anger (mean = 2.5; std. deviation = 1.2) and lowest empathy (mean = 2.9; std. deviation = 0.6).

Figure 4

As listed in Table 3(a), the most frequent noise source across the sites was children's footstep noise, followed by adults' footstep noise and items dropping. In particular, 53% of the participants from Site B reported children's footstep noise as being the major noise source. In addition, it was found that heavyweight impact sources (children and adults' footstep noises) were more dominant than lightweight impact sources. To examine the influence of dominant noise sources on the subjective responses, the two groups who reported the heavyweight and lightweight sources as the dominant noise source were compared. It was found that there was no significant difference between the groups. Table 3(b) also shows the times of the day when the floor impact noise was dominantly heard. It was found that night-time (between 20:00 and 06:00) was the most dominant time for noise exposure, accounting for 54.8% across the sites. The subjective ratings were also compared between the three time periods of noise exposure (20:00 ~ 06:00, 06:00 ~ 09:00, and 09:00 ~ 20:00), but a significant difference was not found.

Table 3

3.2 The effects of non-acoustic factors

In order to investigate the effect of noise sensitivity on the subjective responses, the participants were divided into two groups concerning their noise-sensitivity scores. The mean and median noise-sensitivity scores were 79.4 and 79.0 respectively. The median value was used as a cut-off point to classify the participants. The participants whose noise-sensitivity scores were <= 79 were grouped as the low noise-sensitivity group (*N* = 204) and those with noise-sensitivity scores above 79 were grouped as the high noise-sensitivity group (*N* = 196). The low noise-sensitivity group's mean noise-sensitivity score was 68.7 (std. deviation = 7.3), while that of the high noise-sensitivity group was 90.6 (std. deviation = 7.7). The responses were significantly different between the noise-sensitivity groups across each of the sites (Figure 5). These results indicate that the noise sensitive participants perceived greater annoyance and anger while expressing less empathy compared to those who were less sensitive to noise. The difference in annoyance ratings between the two groups was much greater than the differences in the anger and empathy ratings. However, the differences between the groups were statistically significant for all of the subjective responses.

Figure 5

House ownership is a long-term investment, so it is quite clear that investors are interested in maintaining and increasing the value of their investment [32]. The residents might have different attitudes to the noise sources and events affecting the value of the house. Thus, in the present study, it was hypothesised that house ownership might affect the subjective responses to floor impact noise. In order to examine this assumption, the participants were classified into house owners (*N* = 271) and renters (*N* = 196). As presented in Figure 6, house owners showed greater annoyance and anger ratings than renters, whereas owners demonstrated lower empathy. The differences between house owners and renters were statistically significant across all of the subjective responses. These differences imply that owners perceive floor impact noise more negatively than renters. These also can be understood with respect to the socio-demographic characteristics because the owners were older, had higher income and education levels, and longer residency than renters. Moreover, all of the residents in Site D were classified as renters, so there could be other variables moderating this result. For example, length of residency. Site D was the newest site and thereby the mean length of residency was also the shortest among the four sites.

Figure 6

Furthermore, annoyance, anger, and empathy ratings were compared across the socio-demographic variables (gender, age group, and child(ren) at home). Although females reported higher annoyance and anger ratings (4.1 and 2.3, respectively) than males (4.0 and 2.1, respectively), there was no significant difference between males and females for all of the subjective ratings. It was also found that the participants in their 20s and 60s showed significant differences in their annoyance and anger ratings. The mean annoyance and anger ratings for those in their 60s were 3.1 (std. deviation = 2.6) and 1.8 (std. deviation = 1.0), respectively, while those for the 20s group was 4.6 (std. deviation = 2.7) and 2.5 (std. deviation = 1.2), respectively. The mean empathy rating for the 60s was 3.6 (std. deviation = 0.7), which was significantly higher than that of the 50s (mean = 3.1; std. deviation = 0.8). Moreover, there was no difference between the participants who had one or more children at home and those who did not have any children. Those who had children reported a slightly higher empathy (mean = 3.4; std. deviation = 0.8) than those who did not (mean = 3.3; std. deviation = 0.8), but the difference was not significant.

Table 4 shows the correlation coefficients between the subjective ratings and non-acoustic factors. Noise sensitivity had a strong correlation with the annoyance, anger, and empathy ratings for all sites; it was positively correlated with annoyance and anger while it had a negative correlation with empathy. Fisher's r-to-z transformation [31] was used to test if the correlations between noise sensitivity and subjective ratings were significantly different. It was revealed that noise sensitivity had significantly stronger correlations with anger than annoyance, except in Site D. There was no significantly stronger coefficient between noise sensitivity and annoyance across the sites. However, the smallest correlation coefficients of noise sensitivity with anger and empathy were found in Site D (r = .82 and -.72, respectively) and they were found to be significantly different from the other coefficients at the other sites.

Table 4

3.3 The effects of multiple factors

A number of studies have established relationships between annoyance and exposure level of transportation noise [33, 34]. Several authors also extended the relationship by adding noise sensitivity and socio-demographic variables [24, 35, 36]. Similarly, simple regression models were developed to examine the influence of noise sensitivity and socio-demographic variables on the subjective ratings. However, contrary to environmental noise, it is not practical to measure or predict indoor noise level. Therefore, slab thickness was introduced as an independent variable assuming that indoor noise level decreases as slab thickness increases. In addition to the slab thickness, tested variables were building age, the participants' age, education level, occupation, income, length of residency, and floor area. All of the variables were translated into a 0 ~ 100 scale calculated based on the equation used in previous multiple regression analyses [37]. The multiple regression models are summarised in Table 5. There was no significant bivariate correlation between the slab thickness and annoyance, indicating that the slab thickness itself does not have a strong relationship with annoyance. On the other hand, the slab thickness had a small but significant regression coefficient in the multiple regression model of annoyance with other independent variables. Specifically, the regression model included slab thickness, building age, and noise sensitivity as the independent variables for predicting annoyance. Give that the standardised regression coefficients of noise sensitivity (β = .84) were considerably greater than the others' (βs = .10 and .22 for slab thickness and building age, respectively), it could be assumed that noise sensitivity played the more significant role than others in the prediction of annoyance.

Table 5

4 Discussion

4.1 Slab thickness

This study did not conduct indoor noise measurements because it was not feasible to ask all 400 participants to vacate their houses for the measurements or to place sound level metres in 400 houses. Instead, this study focused on slab thickness, which has been found to be associated with sound insulation performance [17-19]. We examined whether slab thickness affected the subjective responses to floor impact noise. It was revealed that there was not a strong trend between different slab thicknesses and the subjective ratings. The sites with the thinnest slabs (i.e. 150 mm) showed the highest annoyance rating, followed by those of 210 and 180 mm, respectively. In addition, the residents who lived in buildings with 210 mm slabs expressed the highest anger, while the empathy rating of the residents from the site with 180 mm slabs was greater than those with 150 mm slabs. These findings are not consistent with the previous suggestions made in laboratory studies, in that a thicker slab thickness leads to lower noise levels [18, 19], and that the lower the noise levels result in lower annoyance ratings [13, 14]. Instead, this study yielded further evidence supporting the findings of the prior field research [20, 23]. As reported earlier [23], an increase in slab thickness cannot guarantee better acoustic comfort with lower noise levels or fewer noise events in real life since the occurrence of neighbouring noise including floor impact noise is mainly affected by the neighbour's behaviours and activities. Yeon et al. [20] also reported that slab thickness had a minimal correlation with noise levels from a real impact source. Moreover, the results from the multiple linear regression analyses (Table 5) confirmed that the subjective responses to floor impact noise can be explained not just by the acoustic factors such as sound insulation performance from the slab thickness, but also by different non-acoustic factors [38]. Furthermore, impact sound insulation performance is affected by various factors such as dynamic properties of resilient isolator and floor areas. In the present study, the resilient isolators of the Sites C and D had much lower dynamic stiffness compared to those of the Sites A and B which were built before the introduction of domestic guideline of sound insulation performance. In addition, previous studies (e.g. Lee [39]) reported that the heavyweight impact sound insulation performances varied across floor areas for apartments with same floor structure and resilient material. Therefore, some particular features of each site and those of residents need to be compared to one another in order to seek out any potential factors affecting the subjective ratings. Moreover, experimental and numerical approaches [e.g., 40] could be used to predict the heavyweight impact sound insulation performances and to examine the links between objective characteristics and subjective responses.

4.2 Outdoor noise levels

Residents are exposed to outdoor transportation noise (e.g. road traffic noise) as well as indoor building noise (e.g. floor impact noise) in their homes. Contrary to floor impact noise, road traffic noise is stationary and heard continuously; thus, it could be regarded as ambient noise. Previously, Jeon et al. [41] demonstrated that the annoyance ratings of non-stationary noise in combination with road traffic noise were related to different noise levels. Based on this finding, this study hypothesised that the perception of floor impact noise might be affected by outdoor noise levels because of the masking effects [26]. Questionnaire responses from 18 buildings where outdoor noise levels were measured ($N = 244$) were used in order to examine the influence of ambient noise levels on the perception of floor impact noise. Firstly, it was found that the relationship between outdoor noise level (L_{DEN}) and the subjective responses to floor impact noise was not statistically significant. This indicates that the perception of indoor noise is independent of the ambient noise level. Secondly, the outdoor noise levels were categorised into three groups: 1) < 50 dB, 2) 50 ~ 60 dB, and 3) > 60 dB. It was expected that loud ambient noise might reduce the annoyance and anger ratings of floor impact noise by masking intermittent and impulsive noise. However, as shown in Figure 7, the residents who were exposed to outdoor noise levels above 60 dB expressed the highest annoyance and anger ratings with the lowest empathy rating. The annoyance and anger ratings from the buildings with the loudest ambient noise (> 60 dB) were significantly greater than other groups ($p < 0.01$ for both). These results might be because the residents who live in buildings with higher ambient noise levels (> 60 dB) might perceive the noise more negatively than others, and be more sensitive to noise. The mean noise-sensitivity score of this group (> 60 dB) was 81.8, which was much greater than the other groups. Therefore, additional attention would be required to design the floor structure of buildings located in noisy areas. However, in the present study, the measured outdoor noise levels of each building were used rather than the noise levels of each unit. Future research could predict the noise levels of each unit or story using a computer simulation to further test the masking impact of outdoor noise on the perceptions of indoor noise.

Figure 7

4.3 Financial investment

One of the unexpected findings in this study was that the participants from Site C, which used the thickest slabs (i.e. 210 mm), reported higher negative responses (annoyance and anger) compared to those from Sites B and D with thinner slabs (150 and 180 mm, respectively). This result implies that other socio-demographic variables might have affected the subjective responses. It has been known that house owners are concerned about local noise and expect future improvement more than renters. This is mainly because house owners financially invest more into the property than renters [42]. In this study, most of the participants from Sites A, B, and C were house owners, whereas all of the participants from Site D were renters. As has already been shown in Figure 6, house owners reported significantly higher annoyance and anger than renters. Given that most of the renters in this study were from one site (Site D), there is still a remaining question whether the renters in this study could actually be representative. Thus, further investigation is needed into this factor by recruiting the samples with wider ranges of factors. In addition, the floor area was the biggest in Site C so the residents in Sites C must have a greater financial investment than those in the other sites. Therefore, residents who paid more for the properties expect better acoustic comfort, more concern, and were more annoyed by noise in their dwellings [36, 43]. Since this study did not ask the participants how much money they invested into their properties (e.g. house price and mortgage), future research could examine the impacts of the financial investment on the subjective responses. Given that this study found that noise sensitivity had significant impacts on the responses, future research could also assess how financial investment associates with noise sensitivity.

4.4 Empathy

Similar to the previous studies [1-3], children's footstep noise was the dominant noise source in the present study. Those who have children are more likely to be empathetic to children's noise from upstairs [38]. Thus, it was assumed that those who were living with children would report lower annoyance and anger ratings due to empathy toward their neighbours. Confirming the study's hypothesis, the highest empathy ratings were found at Sites B and D, where the number of participants who lived with one or more children was the highest. This result suggests that living with one or more children might lead to greater empathy. This finding is also in agreement with what the previous qualitative study reported; residents who had children expressed more empathy than those who had no children, and consequently, people with empathy tended to make fewer noise complaints [38]. Assuming a lack of empathy may contribute to higher annoyance and anger, the participants were divided into a low empathy group (N = 203) and high empathy group (N = 197). The groups were divided using the median value of the empathy rating (3.33) as a cut-off point. Figure 8 compares the annoyance and anger ratings between the low and high empathy groups. It was found that the high empathy group reported significantly lower annoyance and anger ratings than the low empathy group. It indicates that having empathy towards upstairs neighbours would decrease one's negative perception (e.g. annoyance and anger) regarding neighbour noise. As discussed in the former section, the experience of living with children may help one to be understanding and empathetic towards neighbours particularly those with children.

Figure 8

4.5 General discussion

As plotted in Figure 3, Site D with slab thickness of 180 mm showed the lower annoyance and anger rating than other sites with thicker or thinner slab thicknesses. This result can be explained by considering other factors. First, Site D was most recently built among the sites so it is arguable that new buildings of Site D might have influenced the decrease of the annoyance and anger ratings. Table 5 also showed that the standardised regression coefficients of the building age on the annoyance and anger the ratings were positive (βs = .22 and .45, respectively), indicating that older buildings led to greater annoyance and anger ratings. Second, all the residents at Site D were renters, whereas other sites had a mixture of owners and renters. Significant differences in subjective responses were found between house owners and renters (Figure 6); thus, it could be argued that renters may perceive less annoyance or anger against floor impact noise than owners. However, as discussed previously, there are still challenges that need further investigations to validate the relationship between house ownership and subjective responses. Third, Site D was the only site without railway noise nearby and it had the lowest outdoor noise level. The result showed that those who were exposed to the higher outdoor noise levels (> 60 dB) had higher mean noise-sensitivity score than the other groups.

Given that noise sensitivity had the strongest impacts on the prediction of all the subjective responses in the multiple regression models, the lowest annoyance and anger ratings of Site D could be explained by using the shortest building age, house ownership as being renters, low outdoor noise level, and low noise sensitivity.

As shown in Figure 5, noise sensitivity clearly affected the subjective ratings. This finding is in line with previous studies which have found there to be a significant influence from noise sensitivity on annoyance and emotional ratings [25, 44, 45]. This study also revealed that residents who were from buildings with higher outdoor noise levels reported higher noise sensitivity as well as more of a negative response to floor impact noise. In addition to noise sensitivity, one’s attitude towards one’s neighbours has been suggested to be another variable affecting the subjective responses to floor impact noise because upstairs neighbours are the main source of the noise [38]. However, it has been discussed that the questionnaire assessing the attitude toward the upstairs neighbours needs to be further developed and improved in order to adequately examine its impact on the subjective responses [25, 44]. This study makes the suggestion that the questionnaire can include items about social cohesion or a sense of community. Existing instruments used to measure the sense of community [46, 47] would provide a further understanding of how the attitudinal factors perceived in relation to one’s neighbours need to be measured.

Previous field studies on indoor noise mainly focused on sound insulation performance [11, 12, 17, 20, 48]; thus, they either did not concern real noise sources [11, 12] or did not evaluate the subjective responses to the noise [17, 20, 48]. Ljunggren and his colleagues measured the sound insulation performances of floors using standard sources (e.g. tapping machine and impact ball) in different types of buildings [11, 12]. They also collected the occupants’ subjective responses to the noise but did not measure real noise sources such as human footsteps coming from upstairs. On the other hand, the present study paid attention to the residents' subjective response to real indoor noises. Moreover, this study mainly focused on the slab thickness in order to test previous findings [17-19, 48]. This study has revealed that increased slab thickness cannot guarantee better acoustic comfort because all of the residents are exposed to different levels of noise due to their upstairs neighbours' different activities and behaviours [23]. Future research may consider different characteristics of the noise source (e.g. upstairs neighbours and their activities) and different characteristics of the house and construction (e.g. floor area and resilient materials) when it comes to the examination of floor impact noise levels.

5 Conclusions

The present study aimed to fulfil an existing need, as there was a lack of field research on subjective responses to floor impact noise (e.g. footstep noise induced by upstairs neighbours). A questionnaire was designed to evaluate the residents' subjective responses to the noise and other factors which were assumed to influence the responses. First, self-rated annoyance and two emotional responses (anger and empathy) caused by floor impact noise were assessed. Second, variables on situational (major noise source), personal (noise sensitivity), and socio-demographic (income and length of residency) characteristics were measured. Four sites with different slab thicknesses were recruited for the on-site evaluations. One hundred residents from each site took part in the study, so a total of 400 responses were collected and analysed. Along with the questionnaire, outdoor noise levels were measured at each site in order to investigate the effect of ambient noise levels on the subjective responses to the indoor noise. From the results, the implication was made that the increase in slab thickness was not enough to resolve the negative responses or conflicts between neighbours regarding floor impact noise.

However, as observed in the multiple regressions analysis, it is still necessary to consider slab thickness as one of several factors for predicting how residents respond to indoor noise. Given that sound insulation performance is affected by several factors (e.g., dynamic property of resilient isolator and floor area), the study suggested further research on various acoustic features of residences in order to understand occupants' responses to indoor noise. Noise sensitivity significantly associated with all of the subjective responses, indicating that noise-sensitive residents reported greater annoyance and anger ratings. The house owners reported higher annoyance and anger; however, this finding should be validated with more samples of the renters by focusing on the effects of residents' financial investment on subjective responses. It was also found that residents living in buildings with higher outdoor noise levels reported higher noise sensitivity, annoyance, and anger. This implies that those who were exposed to higher ambient noise levels tended to have higher noise sensitivity, which consequently led them to perceive higher annoyance and anger towards the indoor noise. Since the study used the outdoor noise measurements collected from the top of some buildings, there is a need for additional investigation to predict the noise levels of each unit to test the masking effect of outdoor noise more in-depth.

Acknowledgement

This research was supported by a grant [18RERP-B082204-05] from Residential Environment Research Program funded by Ministry of Land, Infrastructure and Transport of Korean Government.

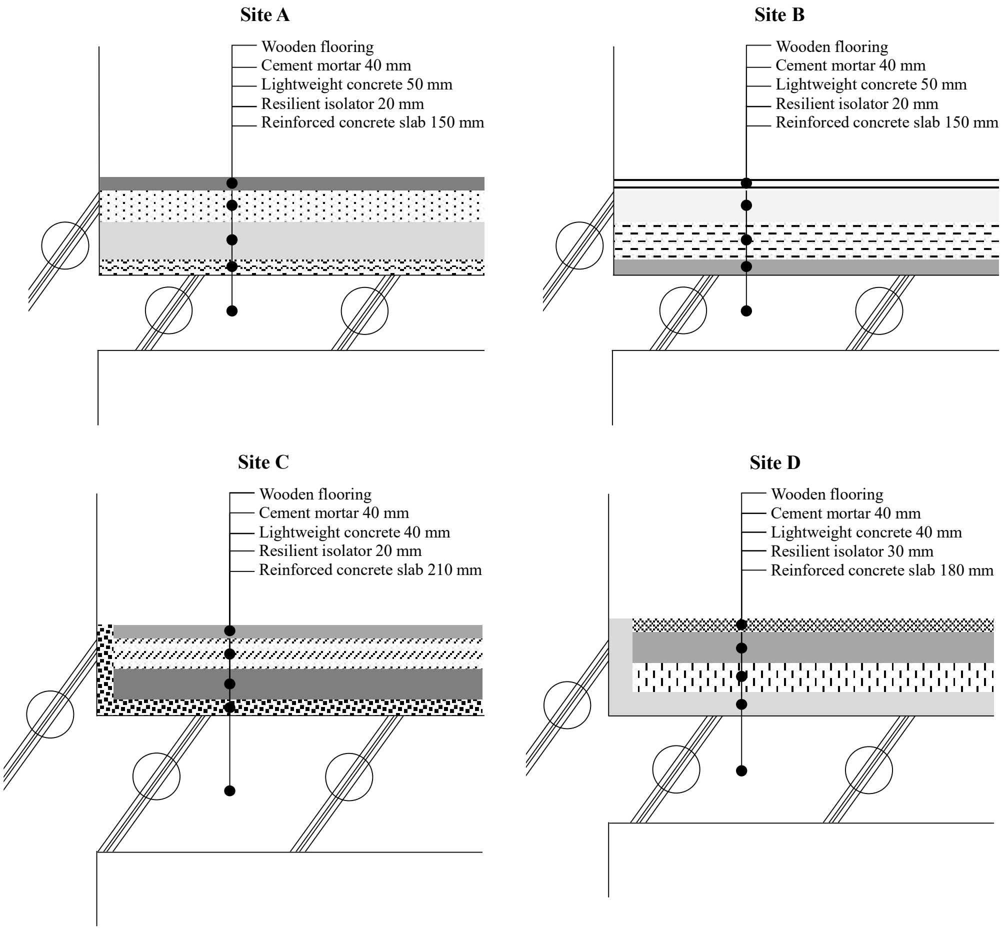


Figure 1. Floor structure of each site. The floors of all sites contained reinforced concrete slab, resilient isolator, lightweight concrete, and cement mortar with different thicknesses and they were finished by wooden floorings.

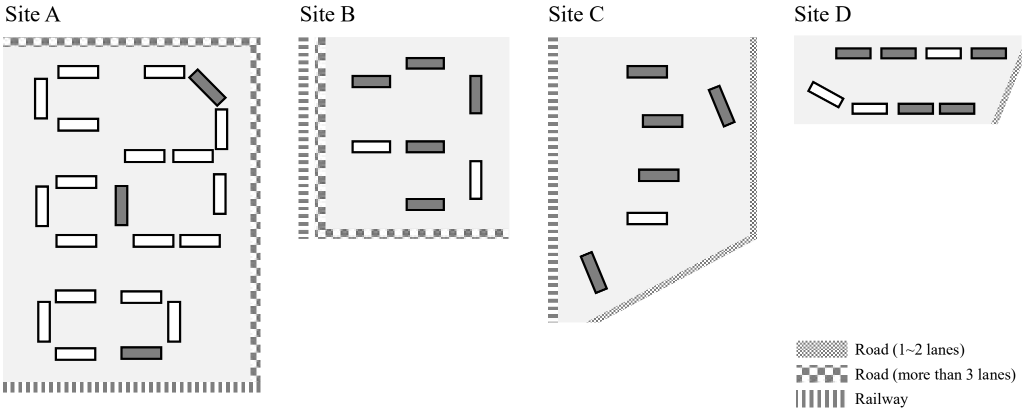


Figure 2. Site plans of four apartment complexes. Grey boxes indicate the buildings where the outdoor noise levels were measured.

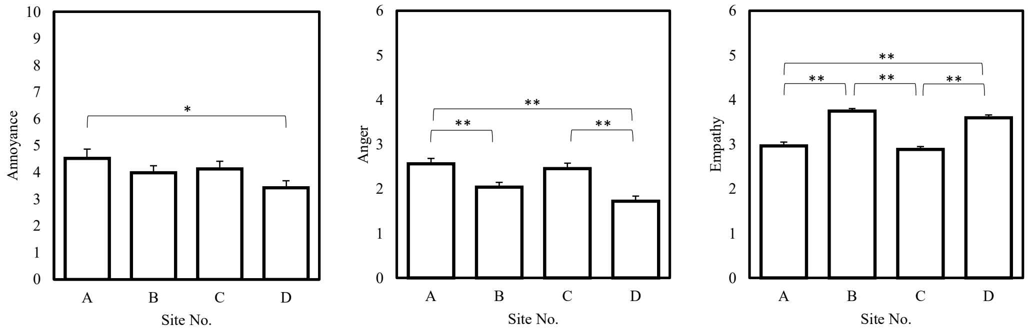


Figure 3. Mean annoyance, anger, and empathy ratings across Sites A, B, C, and D with error bars indicating standard errors (* $p < 0.05$, ** $p < 0.01$).

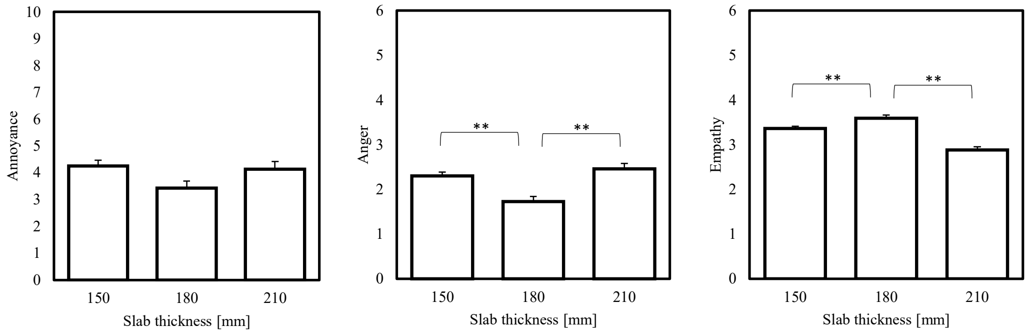


Figure 4. Mean annoyance, anger, and empathy ratings across different slab thicknesses (150, 180, and 210 mm) with error bars indicating standard errors (* $p < 0.05$, ** $p < 0.01$).

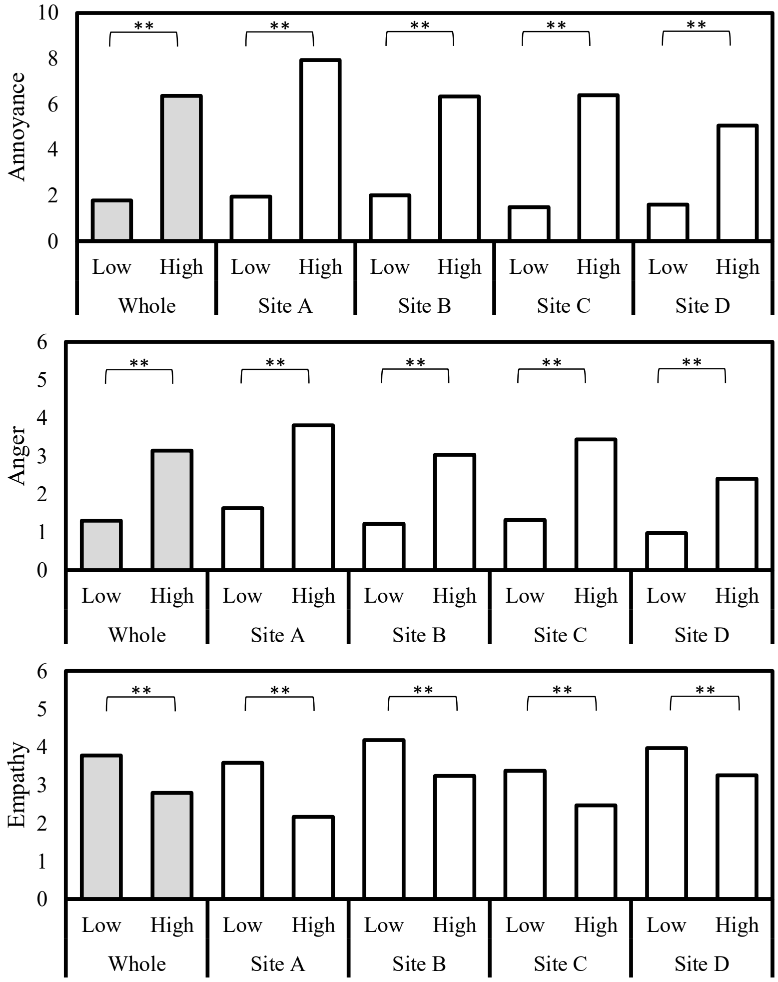


Figure 5. Mean annoyance, anger, and empathy ratings across the low and high noise-sensitivity groups (* $p < 0.05$, ** $p < 0.01$). Grey and white bars represent the responses of the whole sites ($N = 400$) and each site ($n = 100$), respectively.

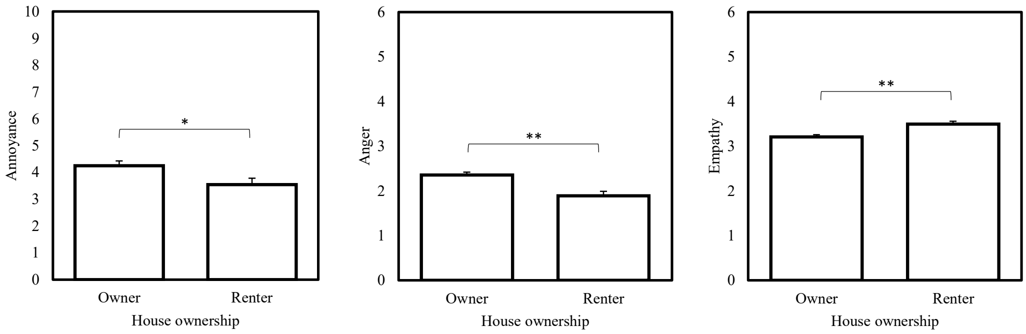


Figure 6. Mean annoyance, anger, and empathy ratings across the house owners and renters with error bars indicating standard errors (* $p < 0.05$, ** $p < 0.01$).

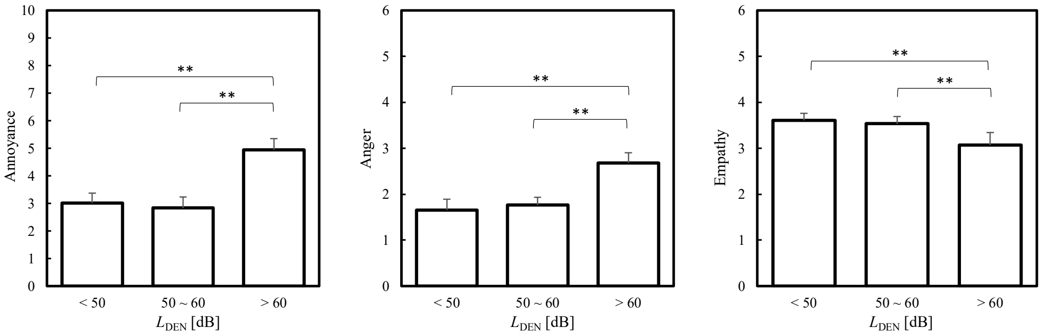


Figure 7. Mean annoyance, anger, and empathy ratings across the outdoor noise levels (L_{DEN}) with error bars indicating standard errors (* $p < 0.05$, ** $p < 0.01$).

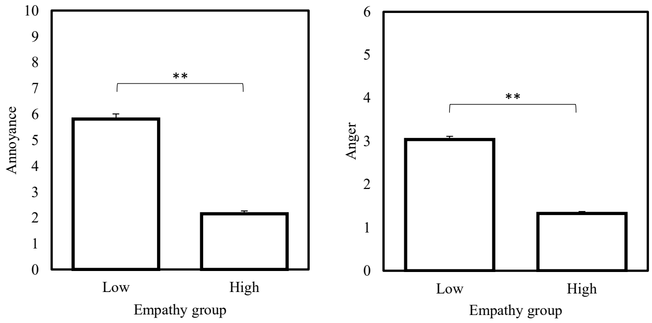


Figure 8. Mean annoyance and anger ratings across the low and high empathy groups with error bars indicating standard errors (* $p < 0.05$, ** $p < 0.01$).

Table 1. Information about the selected sites.

Site No.	A	B	C	D
Construction year	1994	2002	2009	2014
Number of buildings	21	7	7	8
Number of residences	1,827	583	262	522
Number of floors	25	23	15	18
Slab thickness [mm]	150	150	210	180
Floor area [m^2]	58 ~ 85	84	107 ~ 157	52 ~ 60
Outdoor noise level: L_{DEN} [dBA]	49.8 ~ 61.7	58.9 ~ 66.1	56.6 ~ 68.8	44.3 ~ 54.5
Average price per square metre[a]	£2,533	£2,127	£2,047	·

[a] converted South Korean Won (₩) to British Pound (£) with an exchange rate of 1 GBP = 1,500 KRW

Table 2. Information about the participants from each site.

			Site No.			
		Whole	A	B	C	D
Age [years]	Mean	42.9	44.3	41.6	42.5	43.4
	Std. Deviation	10.5	9.6	11.2	10.5	10.6
Gender [*N*]	Male	192	45	46	56	47
	Female	208	55	54	44	53
Child(ren) at home [*N*]	Yes	177	30	58	39	50
	No	223	70	42	61	50
Child(ren) upstairs [*N*]	Yes	218	50	61	59	48
	No	114	35	24	27	28
	Don't know	68	15	15	14	24
Education [*N*]	Middle school or lower	0	0	0	0	0
	High school	73	17	22	13	21
	University/College	293	80	65	74	74
	Postgraduate	34	3	13	13	5
Occupation [*N*]	Full-time employed	206	64	54	45	43
	Part-time employed	58	14	10	21	13
	Self-employed	28	5	5	11	7
	Student	35	6	16	9	4
	Homemaker	69	11	15	11	32
	Unemployed	3	0	0	3	0
	Other	1	0	0	0	1
Income[a] [*N*]	under £13,327	3	1	0	2	0
	£13,327 ~ £19,993	38	10	1	16	11
	£19,993 ~ £26,660	66	20	3	26	17
	£26,660 ~ £33,327	111	35	7	33	36
	£33,327 ~ £39,993	104	24	35	18	27
	more than £39,993	78	10	54	5	9
Length of residency [months]	Mean	85.4	141.1	107.6	59.2	33.7
	Std. Deviation	62.8	78.3	42.5	29.0	9.4
House ownership	Yes (owner)	271	90	94	87	0
	No (renter)	129	10	6	13	100
Noise-sensitivity score	Mean	79.4	78.7	79.6	79.3	80.3
	Std. Deviation	13.3	11.7	11.0	15.6	14.6
Noise-sensitivity group [*N*]	Low	204	57	54	46	47
	High	196	43	46	54	53

[a] converted South Korean Won (₩) to British Pound (£) with an exchange rate of 1 GBP = 1,500 KRW

Table 3. Frequency percentages of major noise source and time of noise exposure.

(a) Major noise source

		Whole	Site No.			
			A	B	C	D
Heavyweight	Child	38.5	32.0	53.0	37.0	32.0
	Adult	25.0	26.0	18.0	26.0	30.0
Lightweight	Furniture	12.3	10.0	15.0	12.0	12.0
	Items	12.5	15.0	10.0	11.0	14.0
	Door	6.3	15.0	0.0	6.0	4.0
	Plumbing	5.5	2.0	4.0	8.0	8.0
	Total	100.0	100.0	100.0	100.0	100.0

(b) Time of noise exposure

	Whole	Site No.			
		A	B	C	D
06:00 ~ 09:00	28.5	41.0	32.0	18.0	23.0
09:00 ~ 12:00	4.5	3.0	2.0	7.0	6.0
12:00 ~ 18:00	3.3	4.0	2.0	4.0	3.0
18:00 ~ 20:00	9.0	10.0	2.0	16.0	8.0
20:00 ~ 06:00	54.8	42.0	62.0	55.0	60.0
Total	100.0	100.0	100.0	100.0	100.0

Table 4. Correlation coefficients between the subjective ratings and the tested variables (* $p < 0.05$, ** $p < 0.01$).

		Noise sensitivity	Age	Education	Occupation	Income	Length of residency	Floor area
Annoyance	Whole	.83**	-.10*	.03	-.01	.03	.06	.03
	Site A	.88**	-.08	.04	-.14	.07	-.07	-.06
	Site B	.87**	-.17	.04	.01	.04	.05	·
	Site C	.88**	-.08	-.03	.26**	.01	-.02	.02
	Site D	.81**	-.09	.05	-.05	.05	.04	.22*
Anger	Whole	.85**	-.12*	.02	-.04	-.04	.08	.10
	Site A	.94**	-.13	.00	-.13	.02	-.13	-.06
	Site B	.91**	-.18	.00	-.01	.02	.02	·
	Site C	.94**	-.11	-.01	.23*	.01	.01	.02
	Site D	.82**	-.11	.01	-.06	.01	.05	.14
Empathy	Whole	-.71**	.08	-.03	.10*	.17**	-.04	-.13**
	Site A	-.92**	.17	-.05	.16	-.06	.09	.07
	Site B	-.90**	.20	.03	.02	-.02	-.03	·
	Site C	-.87**	.01	-.09	-.13	-.06	-.02	.01
	Site D	-.72**	.09	.09	.14	-.01	-.08	-.21*

Table 5. Results from multiple linear regression analyses: model summaries and significant coefficients with annoyance, anger, and empathy (* $p < 0.05$, ** $p < 0.01$).

Dependent Variable	R	R Square	Adjusted R Square	Variables	B	$SE\ B$	β	t	p	95% Confidence Interval for B Lower Bound	Upper Bound
Annoyance	.85	.72	.71	(Constant)	-124.24	6.37		-19.52	**	-136.75	-111.73
				Slab thickness	0.11	0.04	0.10	2.83	**	0.03	0.18
				Building age	0.23	0.04	0.22	6.13	**	0.16	0.30
				Noise sensitivity	2.28	0.07	0.84	31.14	**	2.14	2.43
Anger	.90	.82	.81	(Constant)	-108.48	4.88		-22.23	**	-118.07	-98.88
				Slab thickness	0.30	0.03	0.34	8.88	**	0.23	0.36
				Building age	0.39	0.03	0.45	13.76	**	0.34	0.45
				Participant's age	-0.10	0.03	-0.07	-3.37	**	-0.16	-0.04
				Noise sensitivity	1.95	0.05	0.86	39.52	**	1.86	2.05
				Floor area	-0.09	0.04	-0.06	-2.25	*	-0.16	-0.01
Empathy	.87	.75	.75	(Constant)	165.12	3.82		43.26	**	157.61	172.62
				Slab thickness	-0.44	0.03	-0.77	-17.06	**	-0.49	-0.39
				Building age	-0.37	0.02	-0.66	-16.94	**	-0.42	-0.33
				Participant's age	0.06	0.02	0.06	2.46	*	0.01	0.10
				Occupation	0.06	0.02	0.09	3.35	**	0.02	0.09
				Noise sensitivity	-1.09	0.04	-0.73	-28.86	**	-1.16	-1.01
				Floor area	0.20	0.03	0.23	6.96	**	0.14	0.26

References

[1] Jeon JY, Lee PJ, Kim JH, Yoo SY. Subjective evaluation of heavy-weight floor impact sounds in relation to spatial characteristics. J Acoust Soc Am. 2009;125:2987-94.

[2] Jeon JY, Hong JY, Kim SM, Lee PJ. Classification of heavy-weight floor impact sounds in multi-dwelling houses using an equal-appearing interval scale. Build Environ. 2015;94:821-8.

[3] Jeon JY, Lee PJ, Sato S. Use of the standard rubber ball as an impact source with heavyweight concrete floors. J Acoust Soc Am. 2009;126:167-78.

[4] Statistics Korea. Complete enumeration results of the 2016 population and housing census. Republic of Korea: Statistics Korea; 2017.

[5] Office for National Statistics. Families and Households: 2017. UK: Office for National Statistics; 2017.

[6] Liu L, Rohdin P, Moshfegh B. Evaluating indoor environment of a retrofitted multi-family building with improved energy performance in Sweden. Energ Buildings. 2015;102:32-44.

[7] Floor Noise Management Centre. Monthly report: May 2018. Republic of Korea: Floor Noise Management Centre, Korea Environment Corporation; 2018.

[8] Park KH. Criminal study on the noise: Focused on the floor impact noise dispute. Inha Law Review. 2015;18:297-328.

[9] Lee PJ, Kim JH, Jeon JY. Psychoacoustical characteristics of impact ball sounds on concrete floors. Acta Acust United Ac. 2009;95:707-17.

[10] Nagano K, Horikoshi T. New comfort index during combined conditions of moderate low ambient temperature and traffic noise. Energy and Buildings. 2005;37:287-94.

[11] Ljunggren F, Simmons C, Hagberg K. Correlation between sound insulation and occupants' perception–Proposal of alternative single number rating of impact sound. Appl Acoust. 2014;85:57-68.

[12] Ljunggren F, Simmons C, Öqvist R. Correlation between sound insulation and occupants' perception: Proposal of alternative single number rating of impact sound, Part 2. Appl Acoust. 2017;123:143-51.

[13] Park SH, Lee PJ. Effects of floor impact noise on psychophysiological responses. Build Environ. 2017;116:173-81.

[14] Park SH, Lee PJ, Jeong JH. Effects of noise sensitivity on psychophysiological responses to building noise. Build Environ. 2018;136:302-11.

[15] Jeon JY, Ryu JK, Jeong JH, Tachibana H. Review of the impact ball in evaluating floor impact sound. Acta Acust United Ac. 2006;92:777-86.

[16] Kim MJ, Sohn JY, Kim HS. An Experimental Study on the Effect Factors of Floor Impact Sound Performance for Apartment Housing. Journal of the Architectural Institute of Korea: Planning & Design. 1998;14:167-78.

[17] Huang EHC. Field floor impact noise south-east Queensland (Australia). In: INTER-NOISE and NOISE-CON Congress and Conference. Melbourne, Australia: Institute of Noise Control Engineering; 2014:1634-41.

[18] Kimura S. Development of floor impact sound insulation technology in Japan. J Acoust Soc Am. 1996;100.

[19] Jeon JY, Yoo SY, Jeong Y, Jeong JH. The effect of the design elements of reinforced concrete slab on heavy-weight floor impact noise. Journal of the Architectural Institute of Korea: Planning & Design. 2006;22:329-36.

[20] Yeon JO, Kim KW, Yang KS. A correlation between a single number quantity and noise level of real impact sources for floor impact sound. Appl Acoust. 2017;125:20-33.

[21] Ministry of Construction and Transportation. Criteria on the authorization and management of block structures for floor impact sounds in multi-dwelling houses. Republic of Korea; 2005.

[22] Ministry of Land, Infrastructure and Transport. Presidential decree for the regulations on housing construction standards, etc. (No. 28243). Republic of Korea; 2018.

[23] Park SH, Lee PJ, Lee BK. Levels and sources of neighbour noise in heavyweight residential buildings in Korea. Appl Acoust. 2017;120:148-57.

[24] Job RFS. Community response to noise: A review of factors influencing the relationship between noise exposure and reaction. J Acoust Soc Am. 1988;83:991-1001.

[25] Park SH, Lee PJ, Jeong JH. Emotions evoked by exposure to footstep noise in residential buildings. Plos One. 2018;13:e0202058.

[26] Kryter KD. The Effects of Noise on Man: Academic Press; 1970.

[27] Fields JM, de Jong RG, Gjestland T, Flindell IH, Job RFS, Kurra S, et al. Standardized general-purpose noise reaction questions for community noise surveys: Research and a recommendation. J Sound Vib. 2001;242:641-79.

[28] ISO. Assessment of noise annoyance by means of social and socio-acoustic surveys. Geneva, Switzerland: International Organization for Standardization (ISO); 2003.

[29] Laszlo HE, McRobie ES, Stansfeld SA, Hansell AL. Annoyance and other reaction measures to changes in noise exposure: A review. Sci Total Environ. 2012;435-436:551-62.

[30] Weinstein ND. Individual differences in reactions to noise: A longitudinal study in a college dormitory. J Appl Psychol. 1978;63:458-66.

[31] Steiger JH. Tests for Comparing Elements of a Correlation Matrix. Psychol Bull. 1980;87:245-51.

[32] Friedrichs J, Blasius J. Attitudes of owners and renters in a deprived neighbourhood. European Journal of Housing Policy. 2009;9:435-55.

[33] Rylander R, Björkman M, Åhrlin U, Sörensen S, Berglund K. Aircraft noise annoyance contours: Importance of overflight frequency and noise level. J Sound Vib. 1980;69:583-95.

[34] Fields JM, Walker JG. Comparing the relationships between noise-level and annoyance in different surveys: A railway noise vs. aircraft and road traffic comparison. J Sound Vib. 1982;81:51-80.

[35] Fields JM. Effect of personal and situational variables on noise annoyance in residential areas. J Acoust Soc Am. 1993;93:2753-63.

[36] Miedema HME, Vos H. Demographic and attitudinal factors that modify annoyance from transportation noise. J Acoust Soc Am. 1999;105:3336-44.

[37] Miedema HME, Vos H. Exposure-response relationships for transportation noise. J Acoust Soc Am. 1998;104:3432-45.

[38] Park SH, Lee PJ, Yang KS. Perception and reaction to floor impact noise in apartment buildings: A qualitative approach. Acta Acust United Ac. 2016;102:902-11.

[39] Lee SW. Impact Sound Insulation Characteristics of Floors according to the number of P'yong and Layers. The International Journal of The Korea Institute of Ecological Architecture and Environment. 2004;4:71-8.

[40] Hirakawa S, Hopkins C. Experimental determination of transient structure-borne sound power from heavy impact sources on heavyweight floors with floating floors using an inverse form of transient statistical energy analysis. Appl Acoust. 2018;140:74-82.

[41] Jeon JY, Lee PJ, You J, Kang J. Perceptual assessment of quality of urban soundscapes with combined noise sources and water sounds. J Acoust Soc Am. 2010;127:1357-66.

[42] Schreckenberg D. The association between residential quality of life and aircraft noise annoyance around Frankfurt Airport. In: Acoustics '08 Paris. Paris, France; 2008:9479-84.

[43] Fields JM. Effect of personal and situational variables on noise annoyance: With special reference to implications for en route noise. In: Fields JM, National Aeronautics and Space Administration (NASA); 1992.

[44] Park SH, Lee PJ, Yang KS, Kim KW. Relationships between non-acoustic factors and subjective reactions to floor impact noise in apartment buildings. J Acoust Soc Am. 2016;139:1158-67.

[45] Ryu JK, Jeon JY. Influence of noise sensitivity on annoyance of indoor and outdoor noises in residential buildings. Appl Acoust. 2011;72:336-40.

[46] Chavis DM, Hogge JH, McMillan DW, Wandersman A. Sense of community through Brunswik's lens: A first look. J Community Psychol. 1986;14:24-40.

[47] Buckner JC. The development of an instrument to measure neighborhood cohesion. Am J Community Psychol. 1988;16:771-91.

[48] Baek GO, Mun DH, Han HK, Park HG. Analysis of heavy-weight floor impact noise and vibration of concrete slabs in a residential building. In: World Congress on Advances in Civil, Environmental, and Materials Research. Incheon, Republic of Korea; 2015.

An experimental study of psychophysiological responses to floor impact sounds

Pyoung Jik LEE[1]; Sang Hee PARK[2]

Acoustics Research Unit, School of Architecture, University of Liverpool, UK

ABSTRACT

The present study investigates the adverse effects of floor impact noise using both subjective and physiological methods. A total of 21 subjects participated in the experiments and they were instructed to press a button when they noticed a sound and rate noise annoyance. Heart rate (HR), electrodermal activity (EDA), and respiration rate (RR) were measured while subjects were exposed to floor impact sounds induced by real impact sources and standard heavyweight impact source (impact ball). It was found that noise annoyance and noticeability were highly correlated with noise levels. The floor impact sounds caused by impact ball was found to be more noticeable than real impact sounds when A-weighted maximum noise levels (L_{AFmax}) were greater than 35 dBA. The results showed that listening to floor impact noise lowered HR and raised EDA and RR. The results also indicated that EDA and RR were significantly affected by noise levels.

Keywords: Floor impact sound, Psychophysiological responses I-INCE Classification of Subjects: 63.2, 62.5

1. INTRODUCTION

It is well known that noise has negative non-auditory health effects such as cardiovascular disease, blood pressure, and sleep disturbance (1, 2). Most previous studies have focused on environmental noise. Road traffic noise was found to have impacts on sleeping problems and subjective health complaints (3). It was also reported that road traffic and aircraft noise caused adverse cardiovascular health effects (4). In contrast, few studies investigated the impact of building noise and noise from neighbours on health. Dissatisfaction with neighbour noise was associated with mental health risks (5) and annoyance caused by noise from neighbours was found to have negative effects on physical and mental health (6). However, no one attempted to investigate the influences of floor impact noise on physiological responses although floor impact noise is a major source of noise complaints in apartment buildings (7) and it has a significant impact on health complaints (8).

Moreover, most previous studies on floor impact noise have mainly used standard impact sources to generate noise stimuli (e.g., tapping machine and impact ball). In particular, impact ball has been frequently used (9-11) in the laboratory experiments. Although objective characteristics of the impact ball are similar to human footsteps (12), psychophysiological response might be different across types of impact sources (i.e. standard or real sources).

The present study aims to examine psychophysiological responses to floor impact sounds through laboratory experiments. The floor impact noise were produced by standard impact source (i.e. impact ball) and real impact sources including human footsteps. The participants were asked to evaluate their perceptions of floor impact noise in terms of noticeability and noise annoyance. Three simple physiological measures (heart rate, electrodermal activity, and respiration rate) were also measured when the participants were exposed to the noise.

2. Methods

2.1 Noise stimuli

A total of six different noise sources were used to cover all the impact noises heard in apartment buildings. In general, noise sources were classified into real sources and standard impact source (i.e.

---

[1] P.J.Lee@ liverpool.ac.uk

[2] S.Park@liverpool.ac.uk

impact ball). Additionally, real sources were categorised into two groups according to their physical characteristics: 1) heavyweight impact sources and 2) lightweight impact sources. The heavyweight impact sources were human footsteps such as walking barefoot of an adult, running and jumping of a child, while lightweight impact sources were dropping of a toy and scraping of a chair. Frequency characteristics of the stimuli are shown in Figure 1. All the noises were dominated by low frequencies especially at 63 Hz and there were significant differences across the noise sources. For laboratory experiments, noise levels (L_{AFmax}) of stimuli were adjusted to range between 31.5 and 63 dB in 3.5 dB intervals but the spectral characteristics of the stimuli were not modified.

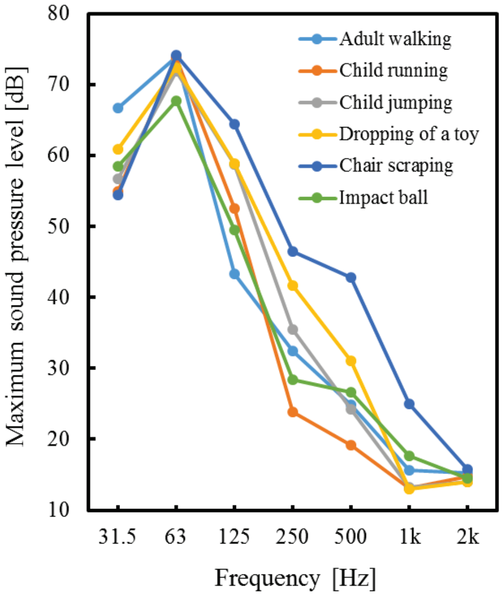


Figure 1. Frequency characteristics of noise stimuli.

2.2 Experimental design

The experiment consisted of five sessions. Of these five sessions, four sessions had 15-minute durations and each session contained 10 or 11 noise stimuli. As listed in Table 1, three sessions (Session 1, 2, and 3) were designed to evaluate psychophysiological responses to noises induced by real impact sources and Session 4 aimed to evaluate the standard impact noises. Sessions 1 and 4 covered the entire range of sound pressure level (31.5 to 63 dBA), whereas Sessions 2 and 3 had narrower ranges of the noise levels than Session 1 and 4.

Table 1. Experimental sessions.

Sessions	Sound pressure level		Noise sources
	L_{AFmax} [dBA]	L_{AE} [dBA]	
1	31.5 ~ 63.0	49.72	Real sources: child running/jumping, adult walking, dropping of a toy, chair scraping
2	31.5 ~ 52.5	43.13	Real sources: child running/ jumping, adult walking, dropping of a toy, chair scraping
3	31.5 ~ 42.0	38.83	Real sources: child running/jumping, adult walking, dropping of a toy
4	31.5 ~ 63.0	46.81	Standard impact source: impact ball
5	31.5 ~ 63.0	-	Both standard and real impact sources

In Sessions 1-4, all the stimuli had same durations of 23 seconds and each stimulus was interspersed with 50 seconds of silence. The stimuli were randomly presented through a loudspeaker to avoid order effects. The first and the last 2-minute silence periods were allocated for resting time.

Session 5 was designed to evaluate short-term noise annoyance of each stimulus and it contained noises caused by both standard and real sources. In Session 5, duration of each noise was eight-second and noise levels of stimuli varied from 31.5 to 63 dBA. An ambient noise was presented to each session from single loudspeaker located in front of the listener. The ambient noise was equalized to have a spectrum shape of noise criterion curve (NC-35) as a representative of typical ventilation noise.

2.3 Measurements of psychophysiological responses

Psychological responses to floor impact noise were assessed in terms of noticeability and noise annoyance. For noticeability, the participants were asked to press a response button when they heard floor impact noise. Two different noise annoyance ratings were obtained. In Sessions 1-4, the participants were asked to rate their noise annoyance after the 15-minute sessions using an 11-point scale (0 = "Not at all" to 10 = "Extremely"). In Session 5, the participants evaluated the annoyance caused by short-term noise exposure of each noise stimulus using magnitude estimation technique. A reference noise of 42 dBA was presented to the participants before they listened to each noise stimulus. They rated noise annoyance of stimulus by assuming annoyance caused by the reference was 100.

In the present study, three simple physiological measures were adopted: 1) heart rate (HR) expressed in beats per minute (BPM), 2) electrodermal activity (EDA) expressed in microsiemens (μS), and 3) respiration rate (RR) expressed in beats per minute (BPM). All the physiological responses were recorded on a laptop computer using a MP 150 WSW digital acquisition system (BIOPAC Systems) and were analysed using AcqKnowledge 4.4 (BIOPAC Systems). The HR was derived from the raw data of electrocardiograph (ECG), while the ECG was measured with electrodes attached to each participant's right wrist and both ankles. The EDA was measured using electrodes attached to the index finger and middle finger of the right hand. The RR was computed from the raw data of respiration, which was measured with a respiration transducer belt worn around the chest. The respiration transducer belt records respiration data by measuring changes in thoracic circumference which occur as one breathes.

2.4 Procedure

The experiments were conducted in an audiometric booth where the background noise level was approximately 25 dBA. For precise measurements, all the electrodes were first attached to the participant's body (right wrist, two fingers of the right hand, and both ankles) to make sure that the gel on each electrode was fully absorbed to skin before the experiment started. Twenty one participants who had experienced exposure to noise from neighbours were invited. The participants were asked to have a seat facing two loudspeakers and a training session was carried out prior to the start of the sessions. The training sessions was 3-minute long and consisted of noises produced by both real and standard impact sources. The subjects attended the five sessions on two separate days and the sessions were randomly presented. The participant was asked to read an e-book using a tablet placed in front of them and asked to imagine they were taking a rest in their own houses.

2.5 Data analysis

In the present study, percentage change (%), which is the percentage of change from baseline to noise exposure, was computed to adjust all the different physiological responses (13-15). Differences in the mean values were tested with the Wilcoxon signed-rank test to estimate the significance of the differences in the psychophysiological responses between real and standard impact sources. Repeated measures analysis of variance (ANOVA) was also used to investigate the effect of noise level and source type on the physiological responses.

3. Results

3.1 Psychological responses

Figure 2 shows the noticeability of floor impact sounds as a function of L_{AFmax}. Differences between the noises caused by standard impact source and real sources were found in the region above 35 dBA. The differences between two sources gradually increased with the increase of noise level but statistically significant differences were found only at two levels (at 42.0 dBA, $p < 0.01$ and at 49 dBA, $p < 0.05$).

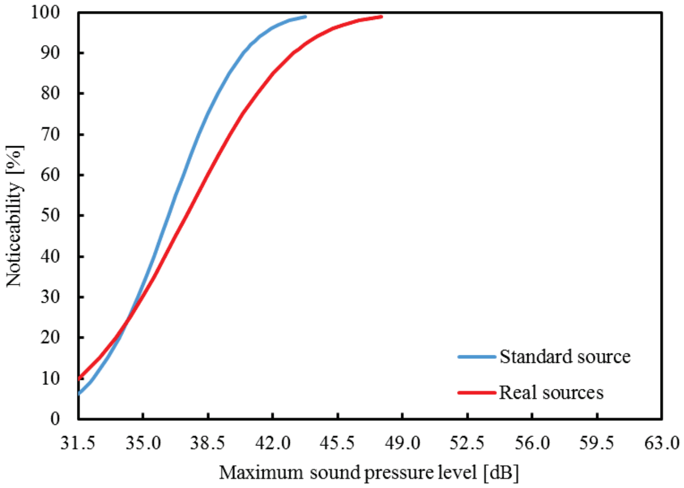
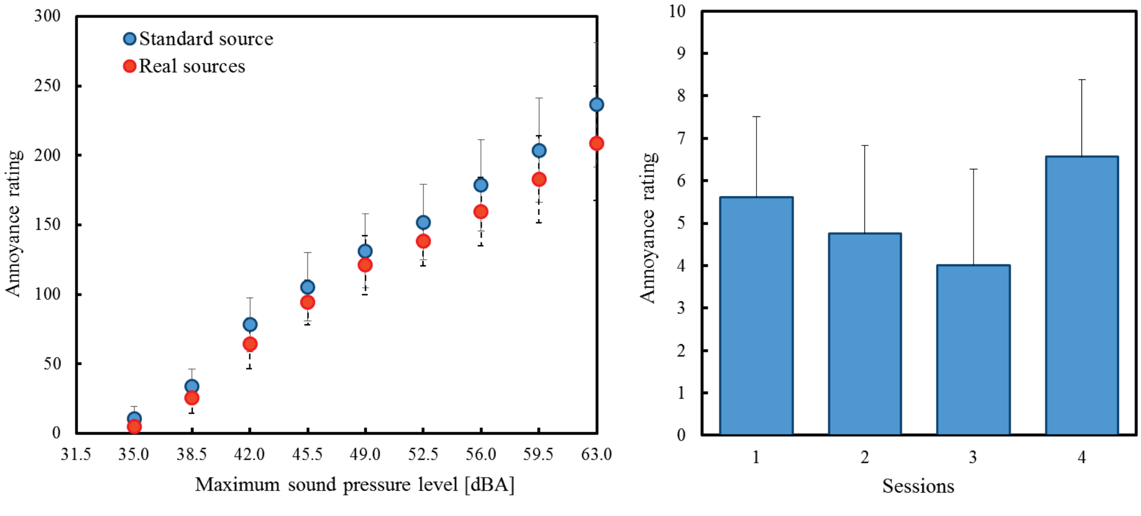


Figure 2. Noticeability as a function of L_{AFmax} across types of noise sources (standard or real impact sources).

As shown in Figure 3(a), noise annoyance ratings increased as noise level increased for both standard and real sources. Differences between standard and real sources were found; the ratings of standard impact source were consistently higher than those of real impact sources. The statistical analysis confirmed that the differences between two sources were statistically significant at all levels. As shown Figure 3(b), the mean annoyance ratings of the Sessions 1-4 were slightly different across the sessions. The greatest annoyance rating was found in the Session 4 which contained noises by the standard impact source. In contrast, the Session 3 with real impact sources showed the lowest noise annoyance rating due to narrow range of noise levels. The Wilcoxon signed-rank tests revealed that the mean annoyance ratings of four sessions were all significantly different ($p < 0.01$).



(a) (b)

Figure 3. Noise annoyance ratings a) as a function of L_{AFmax} across types of noise sources (standard or real impact sources) b) for Sessions 1-4. Error bars indicate standard deviations.

3.2 Physiological responses

The results of psychological responses revealed that more than half of the participants did not notice floor impact noises below 38.5 dBA (L_{AFmax}). Therefore, the noises at 31.5 dBA and 35.0 dBA were excluded from analyses of physiological responses. Figure 4 shows the mean percentage changes of HR, EDA, and RR after noise exposures. Overall, the mean HR decreased but EDA and RR increased when noise stimuli were presented. For HR, the change due to real impact sources were slightly greater than that of standard impact source. The EDA and RR showed opposite tendencies, that is, the standard impact source led to greater change than real sources. However, the differences between standard and real impact sources were not statistically significant for all physiological measures.

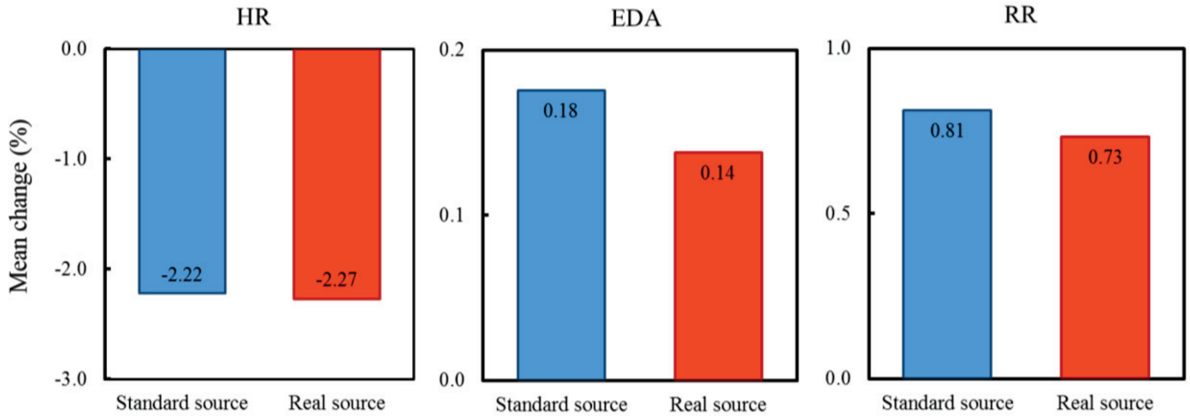


Figure 4. Mean percentage changes of physiological responses across types of noise sources (standard or real impact sources).

Figure 5 presents the changes of HR, EDA, and RR as a function of L_{AFmax}. Repeated measured of ANOVA was used to estimate the significance of differences in changes of physiological responses across types (standard or real sources) and sound pressure levels. The main effects of source types on the physiological responses were not significant, whereas noise level had significant influences on EDA and RR. The interaction between source type and noise level significantly affected EDA, whereas HR and RR were not influenced by the interaction. Correlation analysis revealed that only RR response to real impact noise significantly correlated with noise annoyance measured using the magnitude estimation technique.

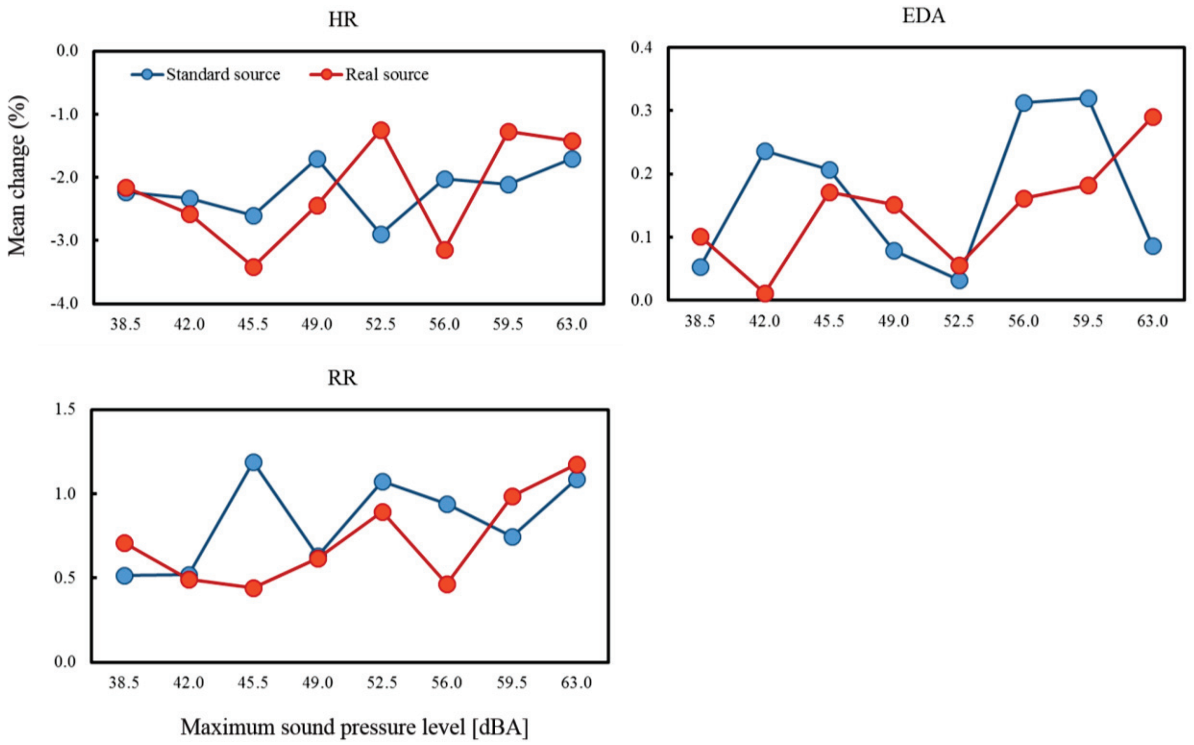


Figure 5. Physiological responses as a function of L_{AFmax} across types of noise sources (standard or real impact sources).

Mean percentage change of each physiological response to the Sessions 1-4 are presented in Figure 6. For HR, the changes due to noise exposures were different across the sessions. The HR increased in Sessions 1 and 4, whereas it decelerated in Sessions 2 and 3. However, statistical differences in HR were not found among four sessions. EDA decreased in all sessions; EDA values in the Sessions 1 and 4 with same noise level variations were significantly different ($p < 0.05$). RR increased across all sessions and significant differences between the sessions were not found. All the physiological responses to the four sessions were not correlated with sound pressure levels and noise annoyance ratings.

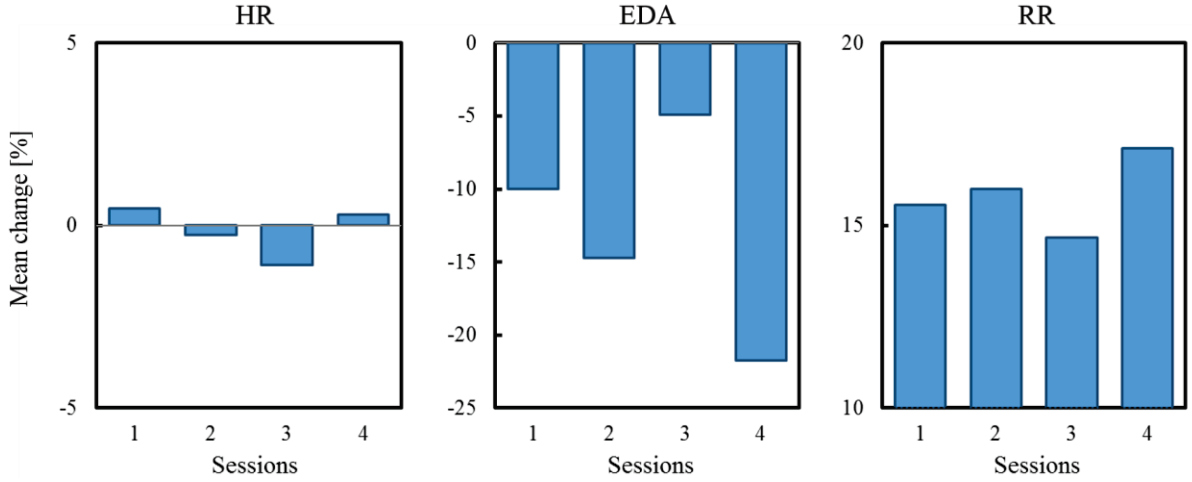


Figure 6. Physiological responses for Sessions 1-4.

4. CONCLUSION

The present study measured the participants' subjective responses (noticeability and noise annoyance) and physiological responses (HR, EDA, and RR) once they were exposed to floor impact noises with different sources and sound pressure levels. It was found that noticeability increased along with increasing sound pressure levels and noise induced by the standard impact source led to higher noticeability than the real impact sources. Noise annoyance ratings also increased with increase of sound pressure level and annoyance ratings between noise sources were significantly different. The physiological responses to each of the 23-second noise stimuli showed deceleration in HR, increase in EDA and RR during the noise exposure. Physiological responses were not affected by the source types (standard or real impact sources) but EDA and RR were influenced by noise levels. The physiological responses to entire noise sessions indicated that HR accelerated in the sessions which contained noise stimuli in higher sound pressure level. EDA declined in all sessions, while RR accelerated in all sessions.

ACKNOWLEDGEMENTS

This research was supported by a grant from a Strategic Research Project (A study on noise reduction solution for adjacency household in apartment house) funded by the Korea Institute of Civil Engineering and Building Technology.

5. REFERENCES

1. Stansfeld SA, Matheson MP. Noise pollution: non-auditory effects on health. British Medical bulletin. 2003;68(1):243-57.
2. Cohen S, Weinstein N. Nonauditory effects of noise on behavior and health. Journal of Social Issues. 1981;37:36-70.
3. Fyhri A, Aasvang GM. Noise, sleep and poor health: Modeling the relationship between road traffic noise and cardiovascular problems. Science of The Total Environment. 2010;408(21):4935-42.
4. Babisch W, Pershagen G, Selander J, Houthuijs D, Breugelmans O, Cadum E, et al. Noise annoyance – a modifier of the association between noise level and cardiovascular health? Sci Total Environ. 2013;452:50-7.
5. Guite H, Clark C, Ackrill G. The impact of the physical and urban environment on mental well-being. Public health. 2006;120(12):1117-26.
6. Maschke C, Niemann H. Health effects of annoyance induced by neighbour noise. Noise Control Eng J.

2007;55(3):348-56.
7. Jeon JY, Jeong JH, Vorländer M, Thaden R. Evaluation of floor impact sound insulation in reinforced concrete buildings. Acta Acustica united with Acustica. 2004;90(2):313-8.
8. Park SH, Lee PJ, Yang KS, Kim KW. Relationships between non-acoustic factors and subjective reactions to floor impact noise in apartment buildings. The Journal of the Acoustical Society of America. 2016;139(3):1158-67.
9. Yoo SY, Lee PJ, Lee SY, Jeon JY. Measurement of sound field for floor impact sounds generated by heavy/soft impact sources. Acta Acust United Ac. 2010;96(4):761-72.
10. Lee PJ, Kim JH, Jeon JY. Psychoacoustical characteristics of impact ball sounds on concrete floors. Acta Acust United Ac. 2009;95(4):707-17.
11. Jeon JY, Lee PJ, Sato S. Use of the standard rubber ball as an impact source with heavyweight concrete floors. J Acoust Soc Am. 2009;126(1):167-78.
12. Jeon JY, Jeong JH, Ando Y. Objective and subjective evaluation of floor impact noise. Journal of Temporal Design in Architecture and the Environment. 2002;2(1):20.
13. Lin HP, Lin HY, Lin WL, Huang ACW. Effects of stress, depression, and their interaction on heart rate, skin conductance, finger temperature, and respiratory rate: sympathetic ‐ parasympathetic hypothesis of stress and depression. Journal of Clinical Psychology. 2011;67(10):1080-91.
14. Miller SB, Ditto B. Individual differences in heart rate and peripheral vascular responses to an extended aversive task. Psychophysiology. 1989;26(5):506-13.
15. Kaiser L. Adjusting for baseline: change or percentage change? Statistics in medicine. 1989;8(10):1183-90.

ICBEN 18 – 22 JUNE ZURICH 2017

12th ICBEN Congress on
Noise as a Public Health Problem

Effects of floor impact noise on people – annoyance and physiological responses

Sang Hee Park[1], Pyoung Jik Lee[1]

[1] Acoustics Research Unit, School of Architecture, University of Liverpool, Liverpool L69 7ZN, United Kingdom

Corresponding author's e-mail address: p.j.lee@liverpool.ac.uk

ABSTRACT

This paper summarises a series of studies focusing on neighbour noise, particularly floor impact noise mostly induced by footsteps. First, an in-depth interview was conducted to understand perception of floor impact noise and a conceptual model indicating the relationships between the key themes was developed. Second, a questionnaire survey was conducted to validate the aforementioned conceptual model. Significant relationships of annoyance and non-acoustic factors were found. Third, 24-hour noise measurements were performed in residential buildings to investigate sources, levels, lengths, and number of occurrences of neighbour noise. Major heavyweight impact sources and range of their noise levels were then identified. Fourth, two laboratory experiments were carried out to investigate annoyance and physiological responses to floor impact noise. Effects of acoustic and non-acoustic factors on the responses were examined. Finally, a sentiment study was conducted to further examine the perception of floor impact noise. Effects of acoustic and non-acoustic factors on sentiment ratings and annoyance were explored.

INTRODUCTION

It has been known that environmental noise annoyance is affected by not only acoustic factors but also non-acoustic factors [1-4]. In particular, aircraft noise annoyance was found to be affected by frequency of over-flight and noise level [1], and annoyance caused by railway, aircraft, and road traffic noises was reported to be influenced by noise level [2]. Noise source is another significant factor that has been found to influence environmental noise annoyance [3-5]. In addition, noise sensitivity has been reported to affect environmental noise annoyance including road traffic or aircraft noise annoyance [6-8]. Moreover, attitude towards either noise or noise source has been known as a significant factor affecting annoyance [9-11]. Despite a number of studies have reported the impact of environment noise on health, few studies have dealt with building noise [12-14]. Noise source was found to affect dwelling noise annoyance [12; 13] and noise sensitivity significantly altered annoyance caused by noises in residential buildings [14].

A series of studies were conducted to understand how residents in multi-family residential buildings react to neighbour noise using different research methods. Firstly, a qualitative study was conducted to understand people's responses when they are exposed to neighbour noise in their homes. The findings from the qualitative study were then validated by the second study using a quantitative method. Next, noise sources, noise levels, lengths, and number of occurrences of major noise events in real residences were identified through field measurements. In addition, two laboratory experiments were designed based on the previous findings and conducted to investigate physiological responses, annoyance, and sentiment changes induced by floor impact noise. Real impact sources as well as standard impact source were used in the laboratory experiments.

PERCEPTION OF AND REACTIONS TO FLOOR IMPACT NOISE

A qualitative study was carried out in order to gain knowledge of how people react when they are exposed to neighbour noise in multi-family residential buildings [15]. From in-depth interviews with a sample of adults, key themes and categories were identified using a methodology of grounded theory [16]. The identified themes and categories were then used for developing a conceptual model explaining responses to floor impact noise.

Conceptual model

In-depth interviews were conducted with residents (N=14) who lived in multi-family residential buildings. The methodology of grounded theory was adopted as it allows substantial data and insight in research data to be yielded, and is useful to comprehend underlying mechanisms of certain phenomena. The interview questions were open-ended and depended on responses of the interviewees. Each interview was manually coded line by line using the interviewee's own words and immediate expressions. The codes were classified into several themes, and those with significant relationships and similarities were grouped together in higher-order categories. No new insight was obtained after the interview of the 13th participant, and theoretical saturation [16] was thus considered to have been attained after one additional interview. The numerous processes of the manual and computerised coding enabled a comprehensive analysis of the data and an identification of the core themes and categories.

The identified themes were grouped into four key categories (noise exposure, noise perception, noise reaction, and intervening conditions). Of the four categories, the term 'intervening conditions' included underlying psychological factors that were observed to interact with the other categories [16]. A conceptual model (Figure 1) was then developed mainly based on previously suggested models of environmental noise [17-19]. This model illustrates relationships among the identified themes under the four categories. Three categories are illustrated to be tied in a loop, and 'intervening conditions' is reciprocally related to this whole loop. It implies 'intervening conditions' have inter-relationships with all the other themes in other categories. Similar to previous studies [26-28], the themes under 'intervening conditions' were found to be closely and reciprocally linked to the themes under the other categories. It was also found that attitudinal factors and noise sensitivity have close relationships with the themes under the other categories such as annoyance and coping, confirming the previous findings from environmental noise [18-21]. Another extended finding of this study is the effects of 'intervening conditions' on noise exposure. Some participants reported that their neighbours produced retaliatory (revengeful) noise after they complained about the noise. Thus, it was hypothesised that a problematic relationship with upstairs neighbours (which is regarded as one of the attitudes to neighbours) may increase the occurrence of retaliatory noise from upstairs.

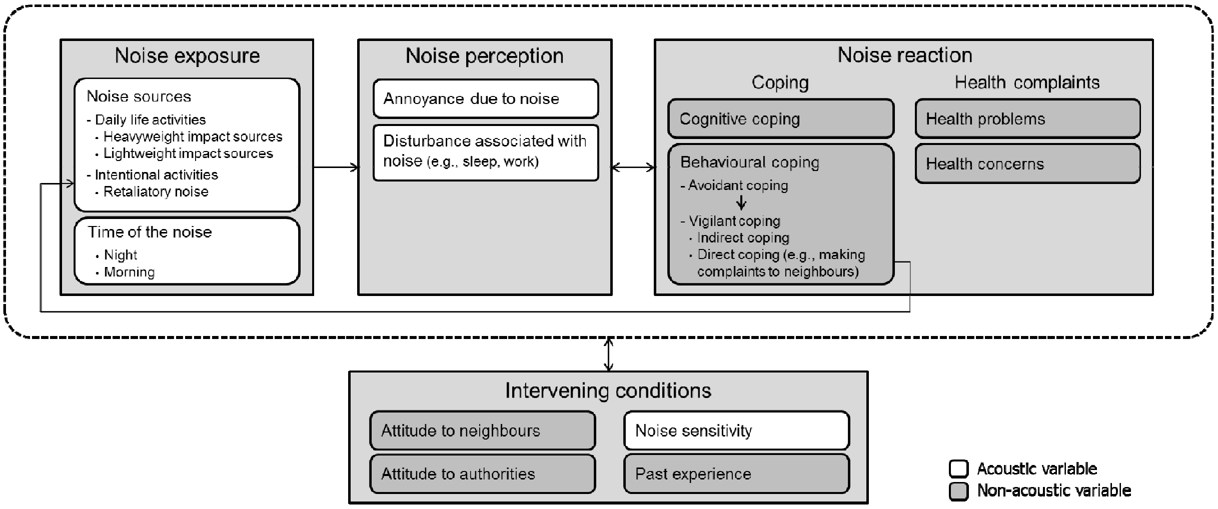


Figure 1: Conceptual model of perception and reaction to floor impact noise [15]

RELATIONSHIP BETWEEN FLOOR IMPACT NOISE ANNOYANCE AND NON-ACOUSTIC FACTORS

A quantitative study was carried out in order to test the previously developed conceptual model [22]. The hypothesised causal model was validated using structural equation modelling (SEM) with survey data from residents living in multi-family residential buildings.

Testing the conceptual model

A causal model was hypothesised based on the previously developed conceptual model. A social survey was then designed to contain question items about noise sensitivity, disturbance, annoyance, health complaints, coping, and attitudinal factors. The responses from the survey (N=487) were analysed using structural equation modelling. This statistical procedure was chosen since it estimates multiple and interrelated relationships simultaneously, calculates measurement error in the estimation process, and describes a model which explains the entire set of relationships [23].

As shown in Figure 2, four of six hypothesised paths were statistically significant. It was found that noise sensitivity increased disturbance; disturbance increased annoyance. Annoyance also significantly affected both coping and health complaints as previous theoretical and empirical studies on environmental noise have suggested [17-21]. However, contrary to previous empirical studies [20; 21], two attitudinal factors had no significant impacts on coping. This might be explained by three reasons. First, different measurement of coping was used. Contrary to the previous studies which asked their participants about cognitive coping [20; 21], this survey focused on asking behavioural coping which was dominantly found in the previous interview study. Second, the noise sources were different. This study measured attitudes to noise source with which the participants can have personal relationships, whereas the noise sources of the other studies [20; 21] were aircraft and railway with which people cannot have personal relationships. The previous studies [20; 21] measured attitudes to noise sources by asking their participants about the importance or financial benefits of the noise sources; but this study asked the participants how close they were with their upstairs neighbours. Third, the relationships between authorities and the noise sources were different. The attitudes towards authorities assessed in this study were not of the kind that the others [20; 21]. The occurrence of aircraft and railway noise can be ascribed to relevant authorities such as airports, railway institutes, or the governments since the noise sources are regarded as being run by the authorities; in contrast, the sources of floor impact noises are simply the upstairs neighbours.

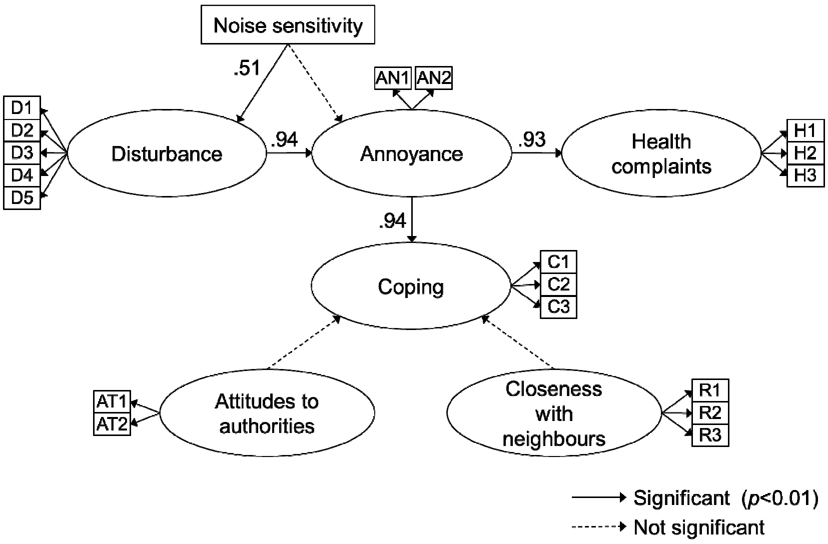


Figure 2: Tested structural equation model [22]

NEIGHBOUR NOISE IN REAL RESIDENCES

Noise measurements for 24 hours were carried out in real residences (*N*=26) to examine different sources of neighbour noise and their levels, lengths, and how many times they occurred [24].

Noise sources, number of occurrences, lengths, and levels

All noise measurements were carried out under unoccupied conditions. All windows were double glazed and closed during the measurements to minimise the effects of outdoor noise. All measurements were also conducted only during weekdays to avoid influences of neighbour's daily activities on the recordings. Only noise events exceeding the threshold levels for day and night based on the WHO recommendation for dwelling noises were analysed: 35 dBA (L_{Aeq}) for day; 30 dBA (L_{Aeq}) and 45 dBA (L_{AFmax}) for night. The threshold L_{AFmax} for the daytime as 50 dBA was also adopted, in accordance with the domestic guidelines of the Korean Government.

As shown in Figure 3, all noise sources were grouped into airborne and structure-borne noises. Of structure-borne noise sources, heavyweight and lightweight impact sources were identified. It was found that structure-borne noise sources occurred dominantly. The number of occurrences of movement of furniture (e.g., chairs, tables etc.) was the largest, followed by dropping of small items, children's running, and adults' walking; they accounted for approximately 80% of all the noise events. Low number of occurrences does not guarantee acoustic comfort in dwellings because this study only counted noise events exceeding threshold noise levels. In addition, lengths of the noise events were very diverse. Door banging was very short (median=3.3s), whereas noise from the plumbing system lasted longer (median=108s). Other sources such as musical instruments showed the largest duration (maximum=428.5s). Since each noise event lasted for different time length, the noise levels of each source were converted into an A-weighted sound exposure level (L_{AE}), which is the equivalent sound level during the event normalised to a period of one second. As presented in Figure 4, PA system showed the highest median noise level, followed by voice of children among the airborne noise sources. Among the structure-borne sources, hammering and door banging produced the highest and lowest median noise levels, respectively.

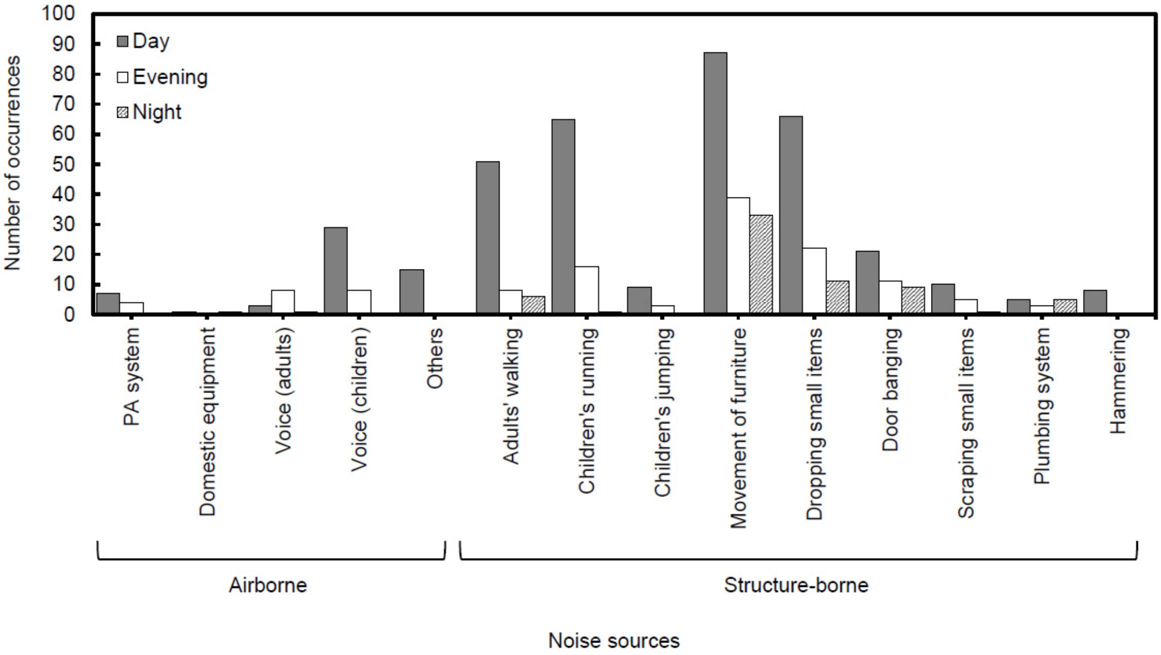


Figure 3: Number of occurrences of different noise sources [24]

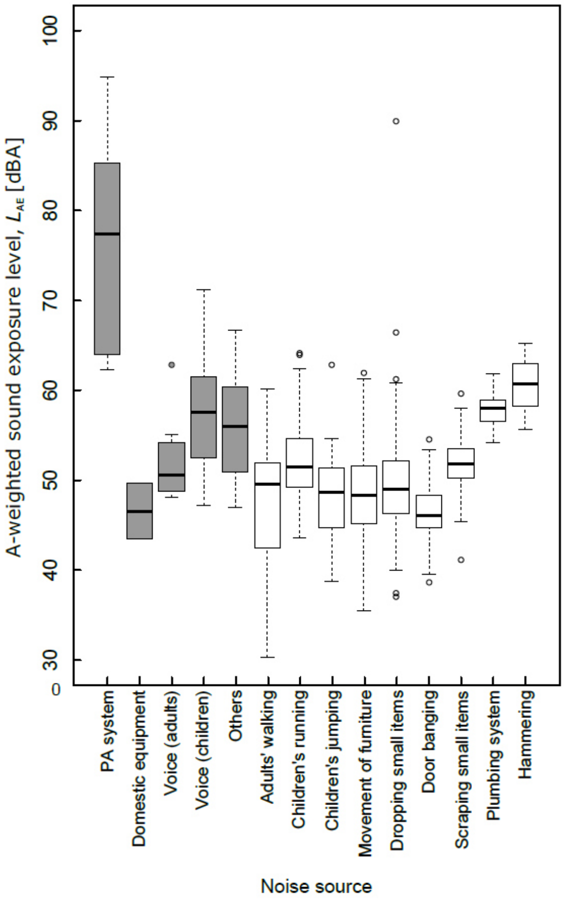


Figure 4: A-weighted sound exposure levels (L_{AE}) of different noise sources: airborne sound sources (grey boxes) and structure-borne sound sources (white boxes) [24]

ANNOYANCE AND PHYSIOLOGICAL RESPONSES TO FLOOR IMPACT NOISE

Two laboratory experiments were conducted to examine annoyance and physiological responses to floor impact noise [25]. Both experiments introduced two different floor impact noises induced by a standard heavyweight impact source (i.e., an impact ball [26]) and real impact sources such as human footsteps. The participants (*N*=21) in the first experiment rated annoyance to 8-second noise stimuli and their physiological responses were measured when 23-second noise stimuli were presented. The second experiment recruited 34 participants and presented 5-minute noise stimuli for measuring all the responses. In both experiments, three simple physiological measures were used: 1) heart rate (HR) expressed in beats per minute (BPM), 2) electrodermal activity (EDA) expressed in microsiemens (μS), and 3) respiratory rate (RR) expressed in beats per minute (BPM). Effects of noise levels, noise sources, noise sensitivity, and duration of noise exposure on psycho-physiological responses were investigated throughout the experiments.

Annoyance

Figure 5 shows the mean magnitude estimation of annoyance for 8-second noise stimuli. It was found that annoyance was affected by noise levels and noise sources. Annoyance increased as the noise level increased for both standard and real impact sources. Annoyance ratings of the standard impact source (i.e., an impact ball) were found to be consistently higher than those of the real impact sources (i.e., lightweight and heavyweight impact sources, such as dropping of a toy and human footsteps). It was notable that the standard deviation (error bars) also increased along with the increasing noise level for both sources. In addition, the differences between the two sources were significant at all levels.

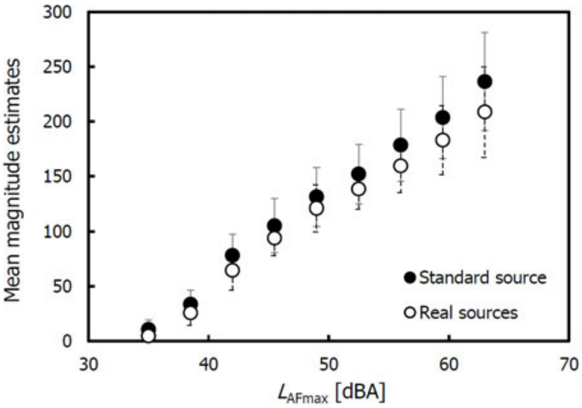


Figure 5: Magnitude estimation of annoyance rated to 23-second noise stimuli [25]

Figure 6 shows the annoyance ratings for 5-minute noise stimuli which were measured by an 11-point scale. Similarly, annoyance was affected by noise levels, noise sources, and noise sensitivity. Annoyance increased as the noise level increased for both the standard and the real impact sources. Annoyance ratings of the reference noise (road traffic noise, RTN) also increased along with the increase of the noise level. However, annoyance ratings of the standard impact source were consistently lower than those of the real impact sources. Statistical significances between the annoyance ratings of the standard and the real impact sources were found at 40 and 60 dBA. This is not consistent with the previous finding in Figure 5 indicating the opposite tendencies. This could be explained by different length of noise stimuli (8-second vs. 5-minute) and different presentation of the standard impact noise. In the first experiment, the standard impact noise stimuli were presented at regular intervals, whereas the impact ball noises were edited to simulate the human footstep noise in the second experiment.

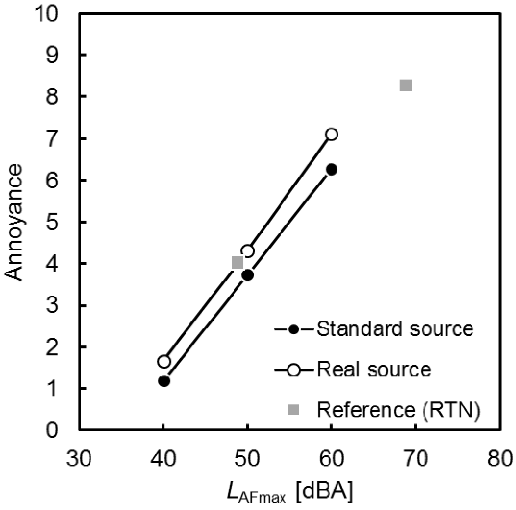
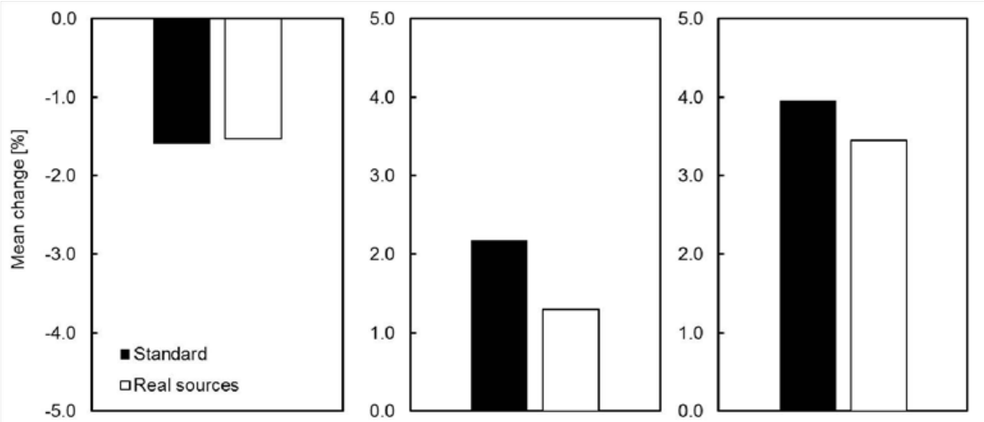


Figure 6: Annoyance rated to 5-minute noise stimuli

Physiological responses

Physiological responses were significantly changed when the 23-second noise stimuli were presented in the first experiment. As shown in Figure 7, heart rate (HR) decelerated, electrodermal activity (EDA) increased, and respiratory rate (RR) accelerated. These changes imply that arousal status was experienced when the noise stimuli were presented [27]. Noise sources (standard vs. real) had no effect on the physiological responses, whereas different noise levels significantly affected changes in EDA and RR.



(a) HR (b) EDA (c) RR

Figure 7: Changes of the physiological responses when the 23-second stimuli were presented [25]

Contrary to the first experiment, both noise levels and noise sources had no impact on the physiological responses when the 5-minute noise stimuli were presented in the second experiment. However, noise sensitivity and duration of noise exposure significantly affected the physiological responses. As presented in Figure 8, HR decelerated, EDA increased, and RR accelerated when the participants were initially exposed to the stimuli, indicating arousal status being experienced [27]; these changes were in agreement with the findings from the first experiment. Additionally, it was found that HR accelerated, EDA decreased, and RR decelerated as the duration of noise exposure increased. In other words, the longer the participants were exposed to the noise, the more their physiological responses habituated [28]. Moreover, differences between the low and high noise-sensitivity groups' physiological responses were significant. The low noise-sensitivity group showed smaller changes (smaller deceleration in HR, and smaller increases in EDA and RR) than the responses of the high noise-sensitive group.

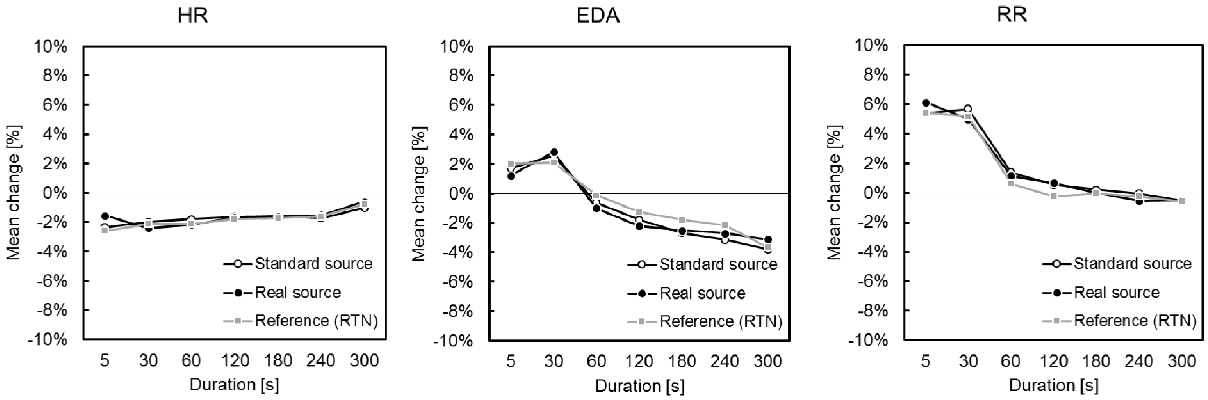


Figure 8: Changes of the physiological responses when the 5-minute stimuli were presented

SENTIMENT ANALYSIS

A sentiment analysis was conducted in order to further examine people's emotion to floor impact noise. Participants were asked to rate anger, sadness, and annoyance when standard impact noise and real impact noise were presented at different noise levels.

Sentiment and annoyance changes

A number of sentiment lexicons were first collected from various data such as the transcripts of the in-depth interview [15], published reports, and online postings about floor impact noise complaints. A preliminary survey was performed with 223 residents living in multi-family residential buildings. A hierarchical clustering method was employed to classify the lexicons into two groups (i.e., anger and sadness). Top 20 lexicons were then chosen to be used as the final lexicons for the main study. The standard impact noise and the real impact noise were presented to participants (*N*=41) at different noise levels in the laboratory. The participants were asked to respond to a questionnaire presenting a list of lexicons related to anger and sadness when the noise stimuli were randomly presented. This study aimed to investigate the influences of noise levels, noise sources, and noise sensitivity on sentiment changes and annoyance.

It was found that the anger and sadness were significantly affected by noise levels and noise sources. As presented in Figure 9, ratings of anger-lexicons and sadness-lexicons increased as the noise level increased. The responses to the real impact noise were constantly higher than those to the standard impact sources above 40 dBA and the differences of the anger between the two sources were significant above 40 dBA. The differences of the sadness between the two sources were also significant above 50 dBA. Annoyance was significantly affected by noise levels but not by noise sources. Similarly, annoyance increased with the increasing noise level for both sources and differences between the two sources were not observed. Noise sensitivity was correlated with annoyance ratings of the real impact noise and anger of the real impact noise. Other non-acoustic factors such as gender, age, length of residency did not have any relationship with the responses. In addition, annoyance had significant correlations with anger and sadness.

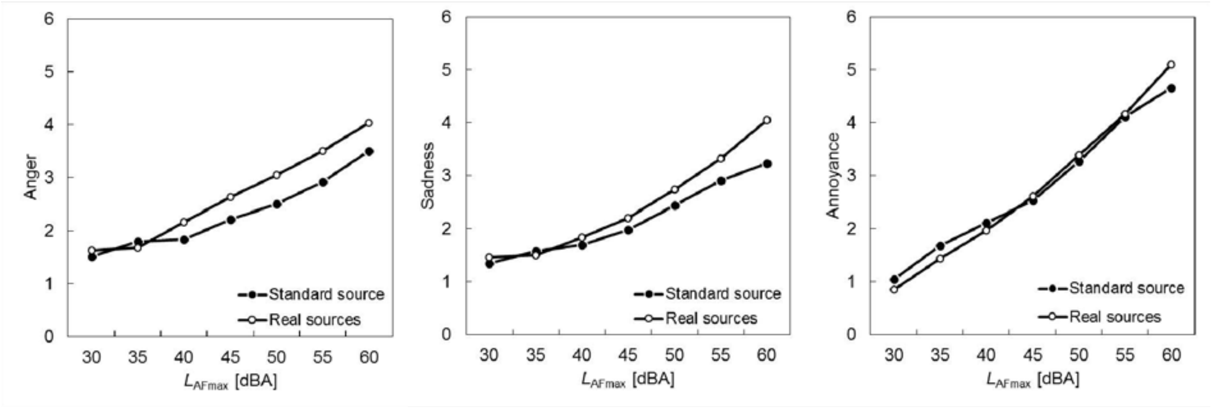


Figure 9: Changes of anger, sadness, and annoyance as the noise level increased

Figure 10 illustrates the subjective ratings of low and high noise-sensitivity groups. All the ratings of the low noise-sensitivity group were consistently lower than those of the high-sensitivity group. The differences between the two groups were significant across the ratings.

Figure 10: Differences between low and high noise-sensitive groups' mean ratings to anger, sadness, and annoyance

CONCLUSION

A series of studies were carried out in order to provide a further understanding of how people perceive and react to neighbour noise heard in their residences. A conceptual model explaining relationships among various factors was developed from the in-depth interviews; this model was then validated by the questionnaire survey. It was found that noise sensitivity had a significant influence on disturbance; disturbance had a significant impact on annoyance, and annoyance had effects on coping and health complaints. Field noise measurements reported that children's running and adults' walking noises were the most dominant heavyweight impact sources, while movement of furniture and dropping of small items were the most dominant lightweight impact sources. Two psycho-physiological experiments showed that noise levels, sources, and noise sensitivity significantly affected annoyance. Noise sensitivity was also found to significantly influence the physiological responses to floor impact noise. Sentiment analysis shows that ratings of anger and sadness increased as the noise level increased, and the ratings were affected by noise sources. Noise sensitivity was significantly correlated with annoyance and both sentiment lexicons (i.e. anger and sadness).

The present study only focused on heavyweight buildings (reinforced concrete) because they are the majority types of residential buildings in South Korea. It would be helpful to investigate lightweight buildings for a wider understanding of psycho-physiological responses to floor impact noise. Particularly, given that residents in South Korea live indoors without shoes, a comparative study between different life-styles (e.g., those who wear shoes indoors) would yield further insight into understanding dwelling noise. In addition, long-term responses in situ could provide a deeper understanding of psycho-physiological responses.

Acknowledgements

This research was supported by a grant from a Strategic Research Project (A study on noise reduction solution for adjacency household in apartment house) funded by the Korea Institute of Civil Engineering and Building Technology.

REFERENCES

[1] Rylander, R., Björkman, M., Åhrlin, U., Sörensen, S., & Berglund, K. (1980). Aircraft noise annoyance contours: importance of overflight frequency and noise level. *Journal of Sound and Vibration, 69*(4), 583-595.

[2] Fields, J. M., & Walker, J. G. (1982). Comparing the relationships between noise-level and annoyance in different surveys – a railway noise vs. aircraft and road traffic comparison. *Journal of Sound and Vibration, 81*(1), 51-80.

[3] Öhrström, E., Björkman, M., & Rylander, R. (1980). Laboratory annoyance and different traffic noise sources. *Journal of Sound and Vibration, 70*(3), 333-341.

[4] Janssen, S. A., Vos, H., Eisses, A. R., & Pedersen, E. (2011). A comparison between exposure-response relationships for wind turbine annoyance and annoyance due to other noise sources. *Journal of the Acoustical Society of America, 130*(6), 3746-3753.

[5] Pedersen, E., & Persson Waye, K. (2004). Perception and annoyance due to wind turbine noise – a dose-response relationship. *Journal of the Acoustical Society of America, 116*(6), 3460-3470.

[6] Stansfeld, S. A., Sharp, D. S., Gallacher, J., & Babisch, W. (1993). Road traffic noise, noise sensitivity and psychological disorder. *Psychological Medicine, 23*(4), 977-985.

[7] Job, R. F. S. (1999). Noise sensitivity as a factor influencing human reaction to noise. *Noise & Health, 1*(3), 57-68.

[8] van Kamp, I., Job, R. F. S., Hatfield, J., Haines, M., Stellato, R. K., & Stansfeld, S. A. (2004). The role of noise sensitivity in the noise-response relation: a comparison of three international airport studies. *Journal of the Acoustical Society of America, 116*(6), 3471-3479.

[9] Öhrström, E., Björkman, M., & Rylander, R. (1988). Noise annoyance with regard to neurophysiological sensitivity, subjective noise sensitivity and personality variables. *Psychological Medicine, 18*(3), 605-613.

[10] Stansfeld, S. A. (1992). Noise, noise sensitivity and psychiatric disorder: epidemiological and psychophysiological studies. *Psychological medicine. Monograph supplement, 22*, 1-44.

[11] Miedema, H. M. E., & Vos, H. (1999). Demographic and attitudinal factors that modify annoyance from transportation noise. *Journal of the Acoustical Society of America, 105*(6), 3336-3344.

[12] Jeon, J. Y., Jeong, J. H., Vorländer, M., & Thaden, R. (2004). Evaluation of floor impact sound insulation in reinforced concrete buildings. *Acta Acustica United with Acustica, 90*(2), 313-318.

[13] Lee, P. J., Kim, J. H., & Jeon, J. Y. (2009). Psychoacoustical characteristics of impact ball sounds on concrete floors. *Acta Acustica United with Acustica, 95*(4), 707-717.

[14] Ryu, J. K., & Jeon, J. Y. (2011). Influence of noise sensitivity on annoyance of indoor and outdoor noises in residential buildings. *Applied Acoustics, 72*(6), 336-340.

[15] Park, S. H., Lee, P. J., & Yang, K. S. (2016). Perception and reaction to floor impact noise in apartment buildings: A qualitative approach. *Acta Acustica United with Acustica, 102*(5), 902-911.

[16] Corbin, J. M., & Strauss, A. (2008). *Basics of qualitative research: techniques and procedures for developing grounded theory* (3 ed.). Thousand Oaks, CA: SAGE.

[17] Lercher, P. (1996). Environmental noise and health: an integrated research perspective. *Environment International, 22*(1), 117-129.

[18] Guski, R. (1999). Personal and social variables as co-determinants of noise annoyance. *Noise & Health, 1*(3), 45-56.

[19] Stallen, P. J. (1999). A theoretical framework for environmental noise annoyance. *Noise & Health, 1*(3), 69-79.

[20] Kroesen, M., Molin, E. J., & van Wee, B. (2008). Testing a theory of aircraft noise annoyance: a structural equation analysis. *Journal of the Acoustical Society of America, 123*(6), 4250-4260.

[21] Pennig, S., & Schady, A. (2014). Railway noise annoyance: exposure-response relationships and testing a theoretical model by structural equation analysis. *Noise & Health, 16*(73), 388-399.

[22] Park, S. H., Lee, P. J., Yang, K. S., & Kim, K. W. (2016). Relationships between non-acoustic factors and subjective reactions to floor impact noise in apartment buildings. *Journal of the Acoustical Society of America, 139*(3), 1158-1167.

[23] Hair, J. F., Black, W. C., Babin, B. J., & Anderson, R. J. (2010). *Multivariate data analysis: a global perspective*: Upper Saddle River: Prentice Hall.

[24] Park, S. H., Lee, P. J., & Lee, B. K. (2017). Levels and sources of neighbour noise in heavyweight residential buildings in Korea. *Applied Acoustics, 120*, 148-157.

[25] Park, S. H., & Lee, P. J. (2017). Effects of floor impact noise on psychophysiological responses. *Building and Environment, 116*, 173–181.

[26] ISO. (2010). Acoustics - Laboratory measurement of sound insulation of building elements, Part 5: Requirements for test facilities and equipment (Vol. ISO 10140-5). Geneva, Switzerland: International Organization for Standardization.

[27] Bradley, M. M., & Lang, P. J. (2007). Emotion and motivation. In J. T. Cacioppo, L. G. Tassinary, & G. G. Berntson (Eds.), *Handbook of psychophysiology* (pp. 581-607): Cambridge University Press.

[28] Jackson, J. C. (1974). Amplitude and Habituation of the Orienting Reflex as a Function of Stimulus Intensity. *Psychophysiology, 11*(6), 647-659.

24th INTERNATIONAL CONGRESS ON SOUND AND VIBRATION
23–27 July 2017, London
ICSV24
23-27JULY 2017
LONDON CALLING

INFLUENCE OF NOISE SENSITIVITY ON PHYSIOLOGICAL RESPONSES TO FLOOR IMPACT SOUNDS

Sang Hee Park and Pyoung Jik Lee

Acoustics Research Unit, School of Architecture, University of Liverpool, Liverpool, L69 7ZN, UK
email: P.J.Lee@liverpool.ac.uk

Jeong Ho Jeong

Building Materials & Environment Team, Fire Insurers Laboratories of Korea, 469-881, Korea

This study investigated the changes in physiological responses to floor impact sounds under a laboratory condition. A total of 34 normal-hearing participants took part in the experiment and were categorised into two groups with low and high noise-sensitivity scores. The participants were exposed to five-minute floor impact sounds produced by a standard impact noise source (an impact ball) and a real impact noise source (human footsteps). For comparison, road traffic noise was used as a reference stimulus. After being exposed to each stimulus, the participants were asked to rate annoyance. During the experiments, heart rate (HR), electrodermal activity (EDA), and respiratory rate (RR) were measured. Annoyance was found to be influenced by noise level, noise source, and noise sensitivity. All physiological responses were found to be changed significantly due to noise exposure. HR decelerated, EDA decreased, and RR decelerated for five minutes of noise exposure. The physiological responses were significantly influenced by noise sensitivity. However, there were no significant effects of noise level or noise source on the physiological responses.

Keywords: floor impact sound, physiological responses, noise sensitivity

1. Introduction

Floor impact sounds have been reported to have significant influences on physical health problems as well as annoyance [1-3]. However, most previous studies about floor impact sounds have used self-report measurements such as a questionnaire survey or interviews [1-3]. In contrast, environmental noise's effects on people have been examined not only by self-report measurements but also with objective methods (e.g., physiological measurements) [4, 5]. Therefore, this study aimed to adopt a physiological measurement as a research method because it could provide additional evidence to understand the adverse effects of exposure to floor impact sounds.

Physiological parameters are responsive measures in various emotional states [6]. In particular, heart rate initially decelerates, electrodermal activity increases, and respiratory gets enhanced when emotion-evoking stimuli are presented [6, 7]. Several studies have introduced physiological measures to investigate the effects of sound stimuli via laboratory experiments [8-10]. There has been little attempt to examine the physiological responses to building noise. A recent study reported that heart rate, electrodermal activity, and respiratory rate were significantly changed after exposure to floor impact noise. However, the duration of sound stimuli (23 seconds) was too short to simulate the situations of real buildings and the impacts on non-auditory factors on physiological responses were not determined.

Noise sensitivity has been recognised as one of the significant factors affecting annoyance [11, 12]; thus, noise sensitivity was hypothesised to influence physiological responses. Since it is well-known that noise level significantly increases self-rated annoyance [13, 14], it was also hypothesised that noise level would affect significant physiological changes. It addition, it was hypothesised that physiological responses will vary across different noise sources [1, 15]. Furthermore, this study hypothesised that duration would influence physiological response.

This study aimed to investigate the effects of noise sensitivity on physiological responses to floor impact sounds. Floor impact noises were recorded in a testing building and field measurement was performed to record road traffic noise. The experiments were carried out in a laboratory with a group of adults to investigate changes in physiological responses. During the laboratory experiments, heart rate, electrodermal activity, and respiratory rate were measured, and the responses for the low and high noise-sensitivity groups were compared.

2. Methods

2.1 Stimuli

The main noise stimuli of this experiment were floor impact sounds. These stimuli were indoor noises induced by a standard impact ball and human footsteps. The floor impact sounds were recorded in a test building constructed as a typical residential building in South Korea, with a low background noise level (25 dBA). The room where the recording was carried out was furnished with wooden flooring. An impact ball [16] dropped from one-metre height was recorded as a standard impact noise while an adult's walking barefoot (70 kg) and a child's running barefoot (24 kg) were chosen as the real impact noise as they were reported to be dominant sources in residential buildings [17]. The floor impact sounds were recorded using a head and torso simulator (Brüel & Kjær Type 4128C), positioned on the sofa in the receiving room downstairs. Noise levels of the floor impact sounds were fixed at 40, 50, and 60 dBA (L_{AFmax}) because noticeability of floor impact sounds was less than 50% at levels below 40 dBA (L_{AFmax}) [18].

In addition, road traffic noise was used as a reference stimulus representing an outdoor environment noise. The noise was recorded next to a motorway. A microphone (Behringer ECM8000) connected to a digital recorder (ZOOM H4n) was positioned 2 m away from the motorway and 1.5 m above the ground. The width of the motorway was 11 m and the average vehicle speed was around 60 km/h. Traffic flow fluctuated due to a roundabout located about 160 m away. A spectral filtering was applied to the recorded noise in order to simulate the noise being heard from indoors under the window closed condition. The closed window with a median degree of isolation was adopted [19]. Noise levels of the road traffic noise were fixed at 40 and 60 dBA ($L_{\mathrm{Aeq,5min}}$). Their L_{AFmax} were 48.8 and 68.8 dBA, respectively.

Fig. 1 shows frequency characteristics of the two floor impact sounds at 60 dBA (L_{AFmax}) and the road traffic noise at 60 dBA ($L_{\mathrm{Aeq,5min}}$). Compared to the road traffic noise, two floor impact noises had dominant sound pressure levels at low frequencies below 125 Hz.

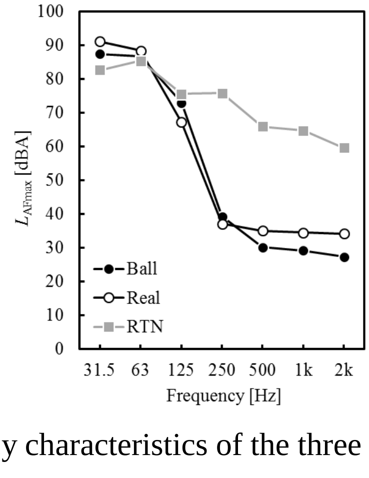


Figure 1: Frequency characteristics of the three types of stimuli.

Contrary to a previous study [18] which used 23-second noise stimuli, the noise stimuli lasted for five minutes in this experiment in order to understand long-term changes in physiological responses. Two minutes of rest period (baseline) was followed by five minutes of noise exposure. All stimuli were randomly presented in order to avoid any possible order effect. In general, sound reproduction through loudspeakers is not sufficient at low frequencies below 63 Hz. Therefore, sounds above 63 Hz were reproduced by a loudspeaker (Genelec 8050A) and low frequency sounds below 63 Hz were presented by a subwoofer (Velodyne MicroVee) placed in front of the participants. A low-pass filter with a cut-off frequency of 63 Hz in the octave band was applied to sounds reproduced by the subwoofer. An additional loudspeaker was used for presenting an ambient noise at 31 dBA.

2.2 Participants

An online screening survey was conducted in order to examine potential participants' noise sensitivity. A link to the survey was sent to people via email who showed interest in participating in the experiment. They were asked to respond to 21 questions regarding noise sensitivity measurement [20]. A total of 34 participants with normal-hearing were chosen based on their responses. Participants included 13 males and 21 females, aged between 30 and 48 (mean=38.8; std. deviation=5.3). Half were in their 30s and the other half were in their 40s. The median noise sensitivity score of the low noise-sensitivity group was 61 (std. deviation=6.6) while the high noise-sensitivity group's score was 99 (std. deviation=5.9). The number in each group was the same (N=17). Thirteen participants were either not married or married but had no child, and the others reported that they had one or more child(ren). Results from the six questions about the participants' attitudes to their upstairs neighbours indicated that 14 participants showed positive attitudes; however, 20 participants reported negative attitudes regarding their upstairs neighbours. The mean length of residency in current accommodations was three years; eighteen subjects had lived in their current residences less fewer than three years, while others had lived in their residences for more than three years. It was found that 12 participants had experience of making noise complaints regarding noise from their upstairs neighbours.

2.3 Procedure

Annoyance was rated after the exposure to each stimulus. Annoyance rating was measured using an 11-point scale. In addition, three physiological responses were measured for the whole duration of rest periods and noise exposures: heart rate (HR), electrodermal activity (EDA), and respiratory rate (RR). All physiological responses were recorded via a data acquisition system (BIOPAC Systems MP150) and were analysed using AcqKnowledge 4.4 (BIOPAC Systems). Two wireless amplifiers were placed just outside the audiometric booth where in which the subject was seated in. The amplifiers received all the measurement data via Bluetooth transmitting mode. HR was derived from raw electrocardiograph data which were measured using three electrodes attached to the subject's right wrist and both ankles. EDA was measured using two electrodes attached to the subject's index and middle finger of the right hand. RR was computed from raw respiration data which were measured through a respiration transducer belt worn around the subject's chest. Due to the variations in the participants' physiological responses, percentage changes (%) from baseline to noise exposure were calculated [21].

Statistical analyses were performed using SPSS for Windows (version 22.0, SPSS Inc., Chicago, IL). Main effects of noise levels, type of sources, and duration were assessed using repeated measures analysis of variance (ANOVA) and Wilcoxon signed ranks test was used to estimate significance of differences between different noise levels and noise sources. Mann-Whitney test to compare differences between the two groups of noise sensitivity. In the present study, p values less than 5% (p<0.05) were considered as statistically significant.

3. Results

As shown in Fig. 2, noise annoyance increased for all the noise sources as the noise level increased. The effect of noise level on annoyance was found to be significant [F(1, 40)=77.20]. In addition, there was also a significant effect of noise source on annoyance [F(1, 33)=20.18]. It was found that annoyance for the real impact noise was higher than the rating for the ball noise and significant differences were found at 40 and 60 dBA (L_{AFmax}). Higher annoyance of the real impact noise can be explained by the stimuli's A-weighted sound exposure level (L_{AE}); the real impact noise stimuli's L_{AE} were slightly higher (0.8~1.3 dB) than the ball noise stimuli. Annoyance for the road traffic noise at 40 dBA ($L_{\mathrm{Aeq,5min}}$) was close to those for the ball and real impact noises at 50 dBA (L_{AFmax}) because L_{AFmax} of them were similar. Likewise, as the L_{AFmax} of road traffic noise at 60 dBA ($L_{\mathrm{Aeq,5min}}$) was greater than all other stimuli, annoyance rating for this stimulus was found to be the biggest.

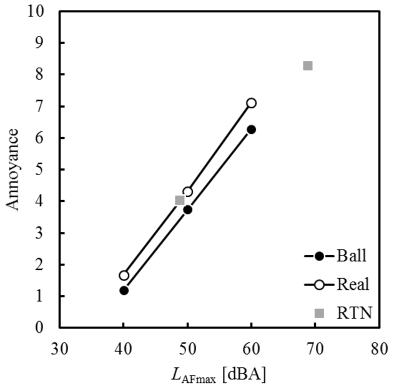


Figure 2: Mean annoyance to difference noise sources at all noise levels.

Fig. 3 describes how annoyance ratings were different between the low and high noise-sensitivity groups. Annoyance rated by the highly sensitive group was found to be higher than the low sensitive group's annoyance. Moreover, the differences between the two noise-sensitivity groups seemed to grow bigger as noise level increased. This trend was consistent for all noise sources. It was found that there were significant differences between the two noise sensitivity groups when the ball noise was presented at 50 and 60 dBA (L_{AFmax}) and the real impact noise at 60 dBA (L_{AFmax}). There was no significant difference found between the two noise-sensitivity groups when the road traffic noise was presented.

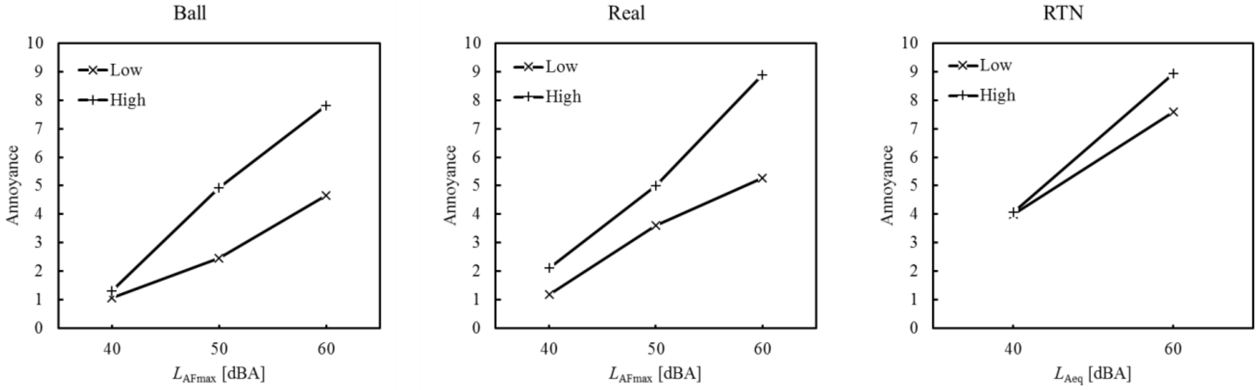


Figure 3: Mean annoyance of the two noise-sensitivity groups to difference noise sources at all noise levels.

Mean changes in HR, EDA, and RR for the three noise sources for five minutes are plotted in Fig. 4. All the physiological responses declined for five minutes. The changes from the baseline were statistically significant for all the physiological responses to all the noise sources. Specifically, mean HR for the ball noise was -1.02% and those for the real impact noise and the road traffic noise were -0.59% and -0.77%, respectively. The decreases of EDA were more than 3% for all the sources; EDA changed -3.81% for the ball noise, -3.10 for the real impact noise, and -3.64 for the road traffic noise. The changes in RR were -0.51% for the two impact noises and -0.58% for the road traffic noise. Mean RR changes were the smallest amongst the three physiological measurements.

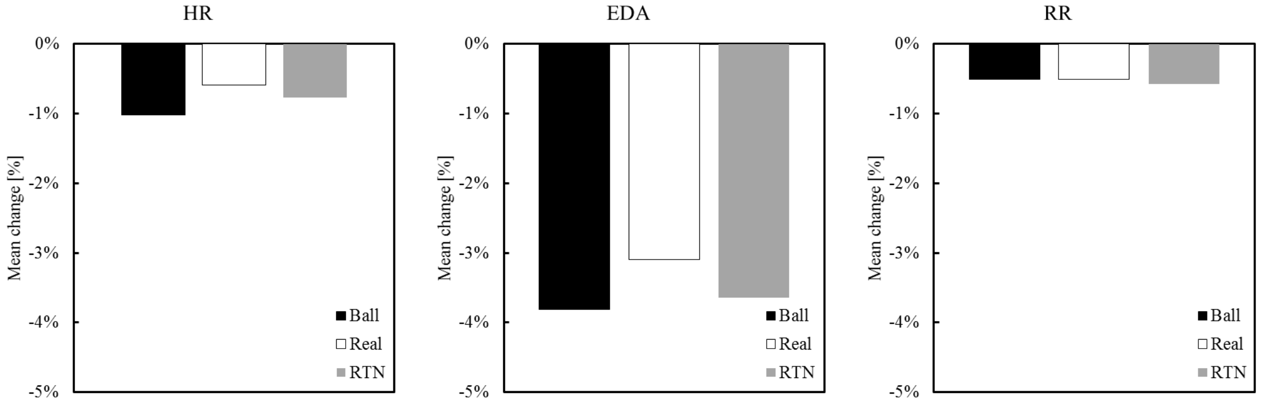


Figure 4: Mean physiological changes to difference noise sources.

Fig. 5 shows mean changes in HR, EDA, and RR for different noise levels. Mean changes in HR showed similar tendencies across the sources, showing quite small changes with increase of noise level. In particular, HR responses to the real impact noise were almost constant within a range between 40 and 60 dBA (L_{AFmax}). It was found that the effects of noise level and impact source type on HR were not statistically significant. Contrary to HR, mean changes in EDA seemed to increase for all the sources as noise level increased; however, the effects of noise level and impact source type were found to have no significant impact on EDA. Similar to the other responses, there were no significant impacts of noise level and impact source type on RR. However, for the road traffic noise, HR and RR were significantly changed while the noise level increased by 20 dBA (L_{AFmax}).

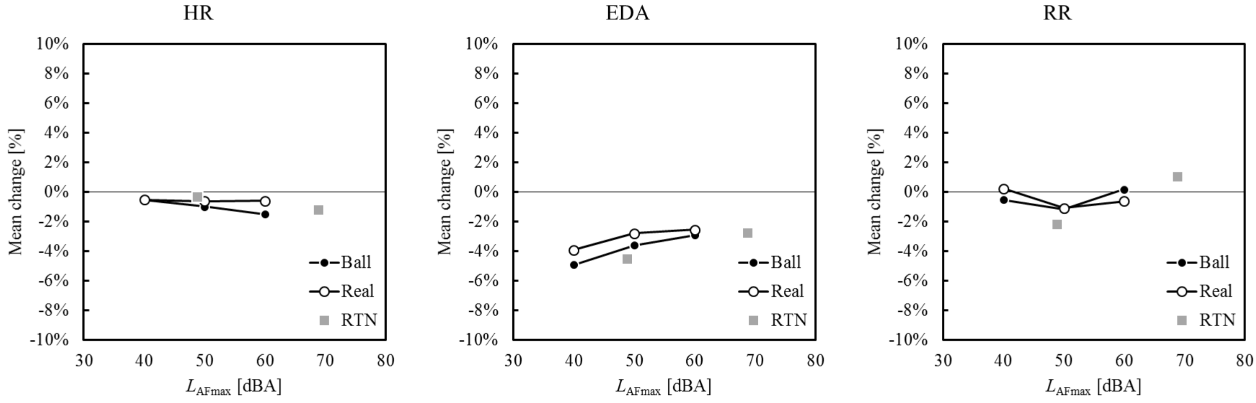


Figure 5: Mean physiological changes to difference noise sources at different noise levels.

In order to examine the effect of noise sensitivity on physiological responses, mean changes of the low and high noise-sensitivity groups were compared in Fig. 6. Significant differences in HR between the groups were found for the ball and the real impact noises. The deceleration in HR of the high noise-sensitivity group was greater than that of the low noise-sensitivity group, thus suggesting that the highly noise sensitive participants exhibit greater changes in HR during the exposure to the floor impact sounds and road traffic noise. Mean changes in EDA appeared to be smaller for the highly sensitive participants for all noise sources. There was a significant difference between the two noise-sensitivity groups when the ball noise was presented. Interesting tendencies were observed from the RR changes. The low sensitive group's RR decelerated whereas the highly sensitive group's RR accelerated. In addition, significantly different RR were found when the ball and the real impact noises were presented.

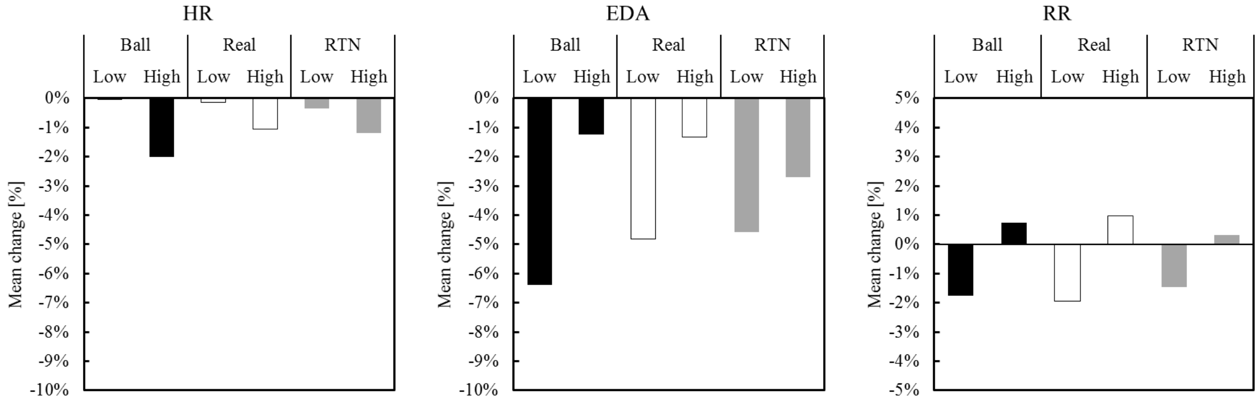


Figure 6: Mean physiological changes of the two noise-sensitivity groups to difference noise sources.

However, it is known that heart rate initially decelerates, electrodermal activity increases and respiration enhances when emotion-evoking stimuli are presented [6, 7]. Park and Lee [18] previously found deceleration in HR, increase in EDA, and acceleration in RR. Since their noise stimuli were more than ten times shorter than the stimuli used in this study, the additional data analysis was carried out in order to compare physiological changes with theirs [18]. As shown in Fig. 7, the changes in the physiological responses were in line with Park and Lee [18]. In addition, standard deviations (representing by the error bars) of the data measured for 30 seconds were much smaller than the responses during five minutes (see Fig. 4).

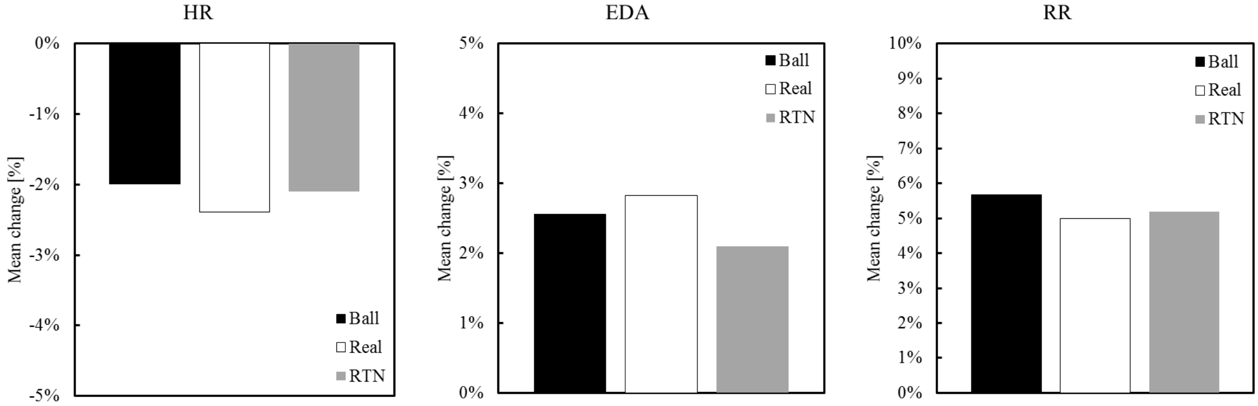


Figure 7: Mean physiological changes of the two noise-sensitivity groups at different durations.

Assuming there would be notable changes occurring within each physiological response during the five minutes of noise exposure, another analysis was carried out. Two more durations were examined (one-minute: 60 seconds, three-minute: 180 seconds) in order to examine the changes during the five minutes. Fig. 8 illustrates how the physiological responses changed during the noise exposure of five minutes. It was found that HR accelerated, EDA decreased, and RR decelerated as time increased. Fig. 8 also shows differences between the two noise-sensitivity groups. The highly sensitive group's HR decelerated more than the other group and this trend was carried on along with the time. EDA and RR of the high noise-sensitivity group increased more than the low noise-sensitivity group and these trends were consistent with the time.

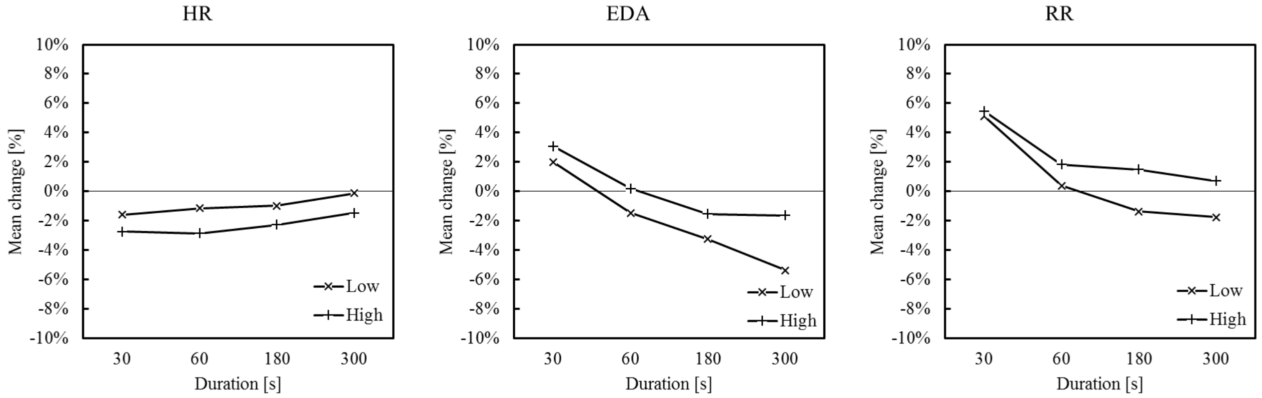


Figure 8: Mean physiological changes of the two noise-sensitivity groups at different durations.

4. Discussion

This study revealed that annoyance was affected by noise level, noise source, and noise sensitivity. It was consistent with previous studies on floor impact sounds and environmental noise [1, 11-15, 18]. However, physiological responses were not influenced by noise levels and noise sources. This showed a good agreement with Hume and Ahtamad [9] who reported that sound pressure level was not related to physiological responses. In addition, the physiological responses were affected by noise-sensitivity. Greater deceleration in HR, smaller decrease in EDA, and acceleration in RR were found from the noise sensitive group after noise exposure for five minutes. This result also confirmed a previous finding [22] of that exposure to low frequency noise caused alterations in cortisol levels among noise sensitive participants.

All the physiological responses represented the arousal status at the initial stages of noise exposure and the responses habituated as the duration increased. An increase of HR change can be seen as habituation or a recovery phase after a certain degree of deceleration occurred by stimuli [23]. Increases in EDA and RR also indicate the experience of arousal and decreases indicate habituation or recovery [23].

5. Conclusion

This study investigated whether noise level, noise source, and noise sensitivity affect annoyance and physiological responses after noise exposure. In addition, changes in physiological responses were examined for different durations of noise exposure. The participants were exposed to floor impact sounds induced by a standard impact source and human footsteps and traffic noise. Annoyance increased as noise level increased, and were affected by different noise sources and noise sensitivity. In addition, all the physiological responses were significantly changed when the participants were exposed to noise. The physiological responses showed that the participants experienced arousal status at the initial stages of noise exposure and habituated as time of noise exposure went by. Noise level and noise source did not have any impact on the physiological responses, whereas noise sensitivity was found to significantly affect physiological responses. The physiological responses of the noise sensitive participants changed more than the low noise-sensitivity group.

ACKNOWLEDGEMENT

This research was supported by a grant (16RERP-B082204-03) from Residential Environment Research Program funded by Ministry of Land, Infrastructure and Transport of Korean government.

REFERENCES

1 Jeon, J. Y., Ryu, J. K. and Lee, P. J. A quantification model of overall dissatisfaction with indoor noise environment in residential buildings, Applied Acoustics, 71 (10), 914-921, (2010).

2 Park, S. H., Lee, P. J., Yang, K. S. and Kim, K. W. Relationships between non-acoustic factors and subjective reactions to floor impact noise in apartment buildings, Journal of the Acoustical Society of America, 139 (3), 1158-1167, (2016).

3 Park, S. H., Lee, P. J. and Yang, K. S. Perception and reaction to floor impact noise in apartment buildings: A qualitative approach, Acta Acustica United with Acustica, 102 (5), 902-911, (2016).

4 Belojevic, G., Jakovljevic, B., Stojanov, V., Paunovic, K. and Ilic, J. Urban road-traffic noise and blood pressure and heart rate in preschool children, Environment International, 34 (2), 226-231, (2008).

5 Haines, M. M., Stansfeld, S. A., Job, R. S., Berglund, B. and Head, J. Chronic aircraft noise exposure, stress responses, mental health and cognitive performance in school children, Psychological medicine, 31 (02), 265-277, (2001).

6 Bradley, M. M. and Lang, P. J. Emotion and motivation. In Cacioppo, J. T., Tassinary, L. G. and Berntson, G. G. (eds), Handbook of psychophysiology. Cambridge University Press, (2007).

7 Boucsein, W. Electrodermal activity, Springer Science & Business Media, (2012).

8 Stansfeld, S. A. Noise, noise sensitivity and psychiatric disorder: epidemiological and psychophysiological studies, Psychological Medicine. Monograph Supplement, 22, 1-44, (1992).

9 Hume, K. and Ahtamad, M. Physiological responses to and subjective estimates of soundscape elements, Applied Acoustics, 74 (2), 275-281, (2013).

10 Bradley, M. M. and Lang, P. J. Affective reactions to acoustic stimuli, Psychophysiology, 37 (02), 204-215, (2000).

11 Job, R. F. S. Community response to noise – a review of factors influencing the relationship between noise exposure and reaction, Journal of the Acoustical Society of America, 83 (3), 991-1001, (1988).

12 Stansfeld, S. A., Sharp, D. S., Gallacher, J. and Babisch, W. Road traffic noise, noise sensitivity and psychological disorder, Psychological Medicine, 23 (4), 977-985, (1993).

13 Schultz, T. J. Synthesis of social surveys on noise annoyance, Journal of the Acoustical Society of America, 64 (2), 377-405, (1978).

14 Miedema, H. M. E. Relationship between exposure to multiple noise sources and noise annoyance, Journal of the Acoustical Society of America, 116 (2), 949-957, (2004).

15 Pedersen, E. and Persson Waye, K. Perception and annoyance due to wind turbine noise – a dose-response relationship, Journal of the Acoustical Society of America, 116 (6), 3460-3470, (2004).

16 Anon., Acoustics - Laboratory measurement of sound insulation of building elements, Part 5: Requirements for test facilities and equipment, International Organization for Standardization, Geneva, Switzerland, (2010).

17 Park, S. H., Lee, P. J. and Lee, B. K. Levels and sources of neighbour noise in heavyweight residential buildings in Korea, Applied Acoustics, 120, 148-157, (2017).

18 Park, S. H. and Lee, P. J. Effects of floor impact noise on psychophysiological responses, Building and Environment, 116, 173–181, (2017).

19 Lee, P. J., Shim, M. H. and Jeon, J. Y. Effects of different noise combinations on sleep, as assessed by a general questionnaire, Applied Acoustics, 71 (9), 870-875, (2010).

20 Weinstein, N. D. Individual differences in reactions to noise: a longitudinal study in a college dormitory, Journal of Applied Psychology, 63 (4), 458-466, (1978).

21 Kaiser, L. Adjusting for baseline: change or percentage change?, Statistics in Medicine, 8 (10), 1183-1190, (1989).

22 Persson Waye, K., Bengtsson, J., Rylander, R., Hucklebridge, F., Evans, P. and Clow, A. Low frequency noise enhances cortisol among noise sensitive subjects during work performance, Life sciences, 70 (7), 745-758, (2002).

23 Watson, J., Gaind, R. and Marks, I. Physiological habituation to continuous phobic stimulation, Behaviour Research and Therapy, 10 (3), 269-278, (1972).

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

Sang Hee Park
Pyoung Jik Lee
Acoustics Research Unit, School of Architecture, University of Liverpool, Liverpool, L69 7ZN, UK.

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.

PACS no. 43.50.Qp, 43.64.Ri

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 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.

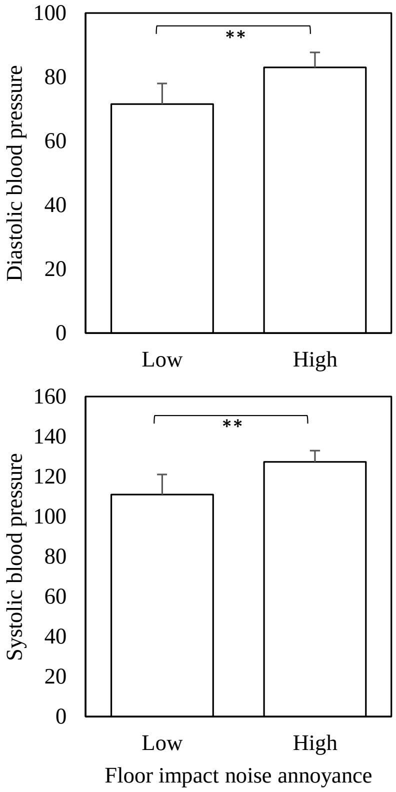


Figure 1. Blood pressure between low and high floor impact noise annoyance groups. * $p < 0.05$, ** $p < 0.01$.

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

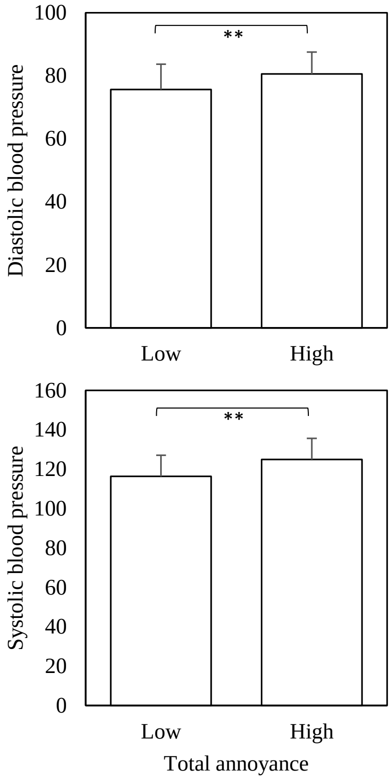
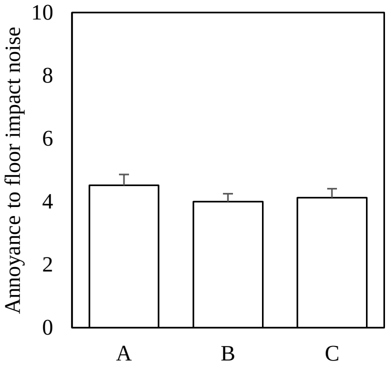
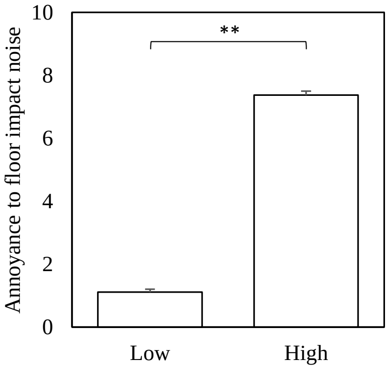


Figure 2. Blood pressure between low and high total annoyance groups. * $p < 0.05$, ** $p < 0.01$.

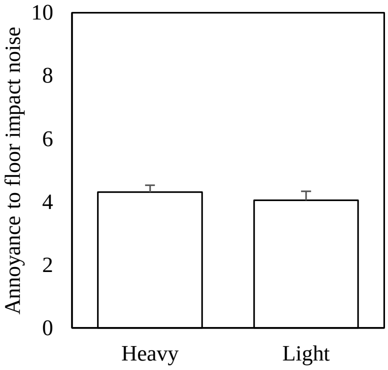
age of buildings and slab thickness would affect the annoyance ratings of floor impact noise; however, one-way analyses of variance confirmed that there was no significant difference between the sites (F(2,296) = .834, $p = .436$). Participants were classified into low and high noise sensitivity groups 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.



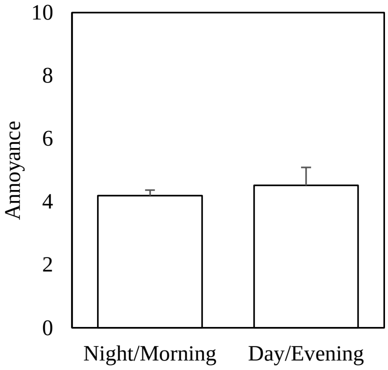
(a) Sites



(b) Noise sensitivity



(c) Noise source



(d) Time

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

As listed in Table II, children’s footsteps were the most dominant source of heavyweight floor impact noise preceding adults’ footsteps, and furniture scraping. In addition, night-time (between 20:00 and 06:00) was the most dominant

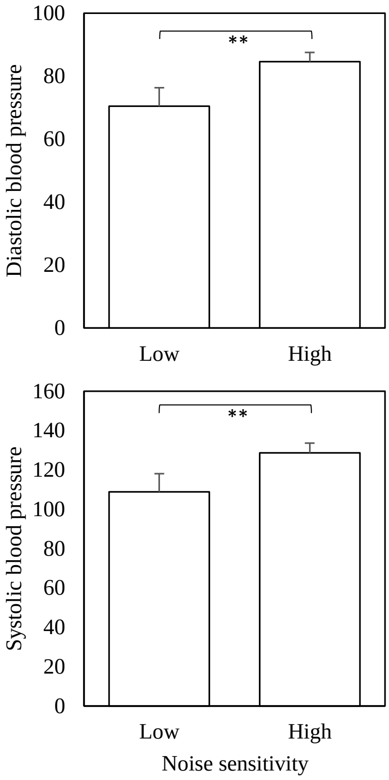


Figure 4. Blood pressure between low and high noise sensitivity groups. * $p < 0.05$, ** $p < 0.01$.

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.

References

[1] J. Y. Jeon: Subjective evaluation of floor impact noise based on the model of ACF/IACF. Journal of Sound and Vibration 241 (2001) 147-155.

[2] J. Y. Jeon, J. K. Ryu, P. J. Lee: A quantification model of overall dissatisfaction with indoor noise environment in residential buildings. Applied Acoustics 71 (2010) 914-921.

[3] S. H. Park, P. J. Lee, K. S. Yang, K. W. Kim: Relationships between non-acoustic factors and subjective reactions to floor impact noise in apartment buildings. Journal of the Acoustical Society of America 139 (2016) 1158-1167.

[4] S. H. Park, P. J. Lee, K. S. Yang: Perception and reaction to floor impact noise in apartment buildings: a qualitative approach. Acta Acustica United with Acustica 102 (2016) 902-911.

[5] S. H. Park, P. J. Lee: Effects of floor impact noise on psychophysiological responses. Building and Environment 116 (2017) 173–181.

[6] S. H. Park, P. J. Lee, J. H. Jeong: Effects of noise sensitivity on psychophysiological responses to building noise. Building and Environment 136 (2018) 302-311.

[7] V. Regecová, E. Kellerová: Effects of urban noise pollution on blood pressure and heart rate in preschool children. Journal of hypertension 13 (1995) 405-412.

[8] E. van Kempen, I. van Kamp, P. Fischer, H. Davies, D. Houthuijs, R. Stellato, C. Clark, S. Stansfeld: Noise exposure and children's blood pressure and heart rate: the RANCH project. Occupational and Environmental Medicine 63 (2006) 632-639.

[9] Y. Aydin, M. Kaltenbach: Noise perception, heart rate and blood pressure in relation to aircraft noise in the vicinity of the Frankfurt airport. Clinical Research in Cardiology 96 (2007) 347-358.

[10] G. Belojevic, B. Jakovljevic, V. Stojanov, K. Paunovic, J. Ilic: Urban road-traffic noise and blood pressure and heart rate in preschool children. Environment International 34 (2008) 226-231.

[11] W. Babisch: Road traffic noise and cardiovascular risk. Noise and Health 10 (2008) 27.

[12] G. Belojevic, M. Saric-Tanaskovic: Prevalence of arterial hypertension and myocardial infarction in relation to subjective ratings of traffic noise exposure. Noise and Health 4 (2002) 33.

[13] P. A. James, S. Oparil, B. L. Carter, et al.: 2014 evidence-based guideline for the management of high blood pressure in adults: Report from the panel members appointed to the eighth joint national committee (jnc 8). JAMA 311 (2014) 507-520.

[14] N. D. Weinstein: Individual differences in reactions to noise: a longitudinal study in a college dormitory. Journal of applied psychology 63 (1978) 458-466.

[15] J. K. Ryu, J. Y. Jeon: Influence of noise sensitivity on annoyance of indoor and outdoor noises in residential buildings. Applied Acoustics 72 (2011) 336-340.

[16] J. Y. Jeon, J. K. Ryu, J. H. Jeong, H. Tachibana: Review of the impact ball in evaluating floor impact sound. Acta Acustica United with Acustica 92 (2006) 777-786.

[17] S. H. Park, P. J. Lee, B. K. Lee: Levels and sources of neighbour noise in heavyweight residential buildings in Korea. Applied Acoustics 120 (2017) 148-157.

[18] J. M. Fields: Reactions to environmental noise in an ambient noise context in residential areas. Journal of the Acoustical Society of America 104 (1998) 2245-2260.

[19] J. M. Fields: Impact of ambient noise on noise annoyance: an assessment of the evidence. Proceedings of INTER-NOISE and NOISE-CON Congress and Conference Proceedings, 1992.