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An experimental study of psychophysiological responses to floor impact sounds

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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.

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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.

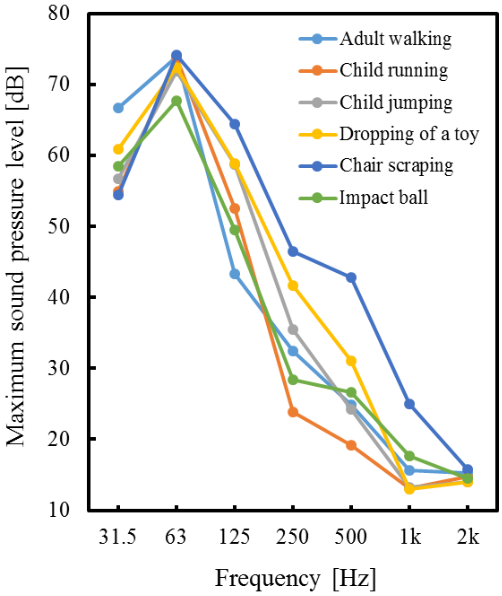


Figure 1. Frequency characteristics of noise stimuli.

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, $p < 0.05$).

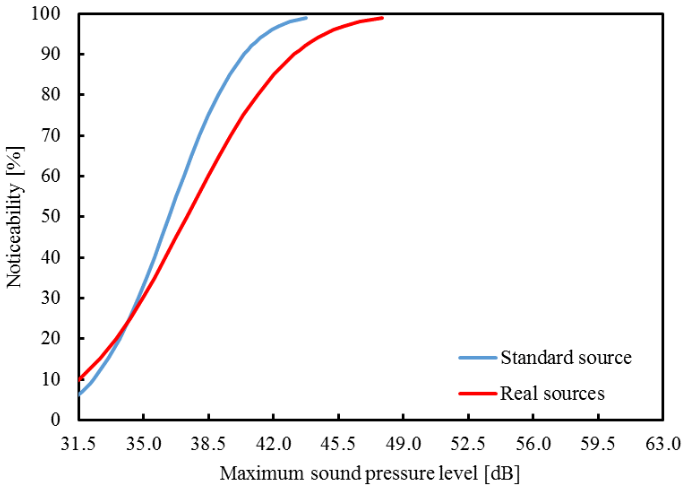
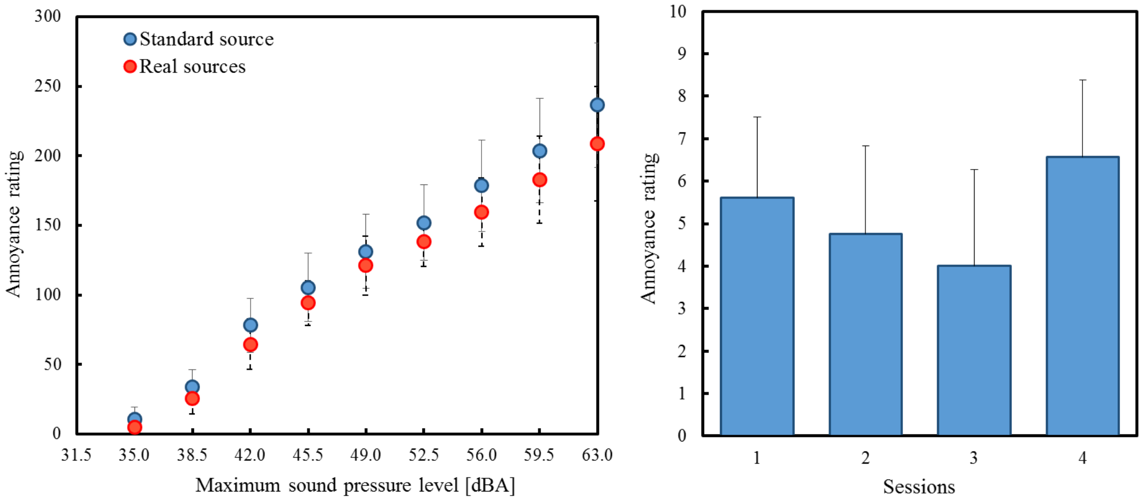


Figure 2. Noticeability as a function of L_{AFmax} across types of noise sources (standard or real impact sources).

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.

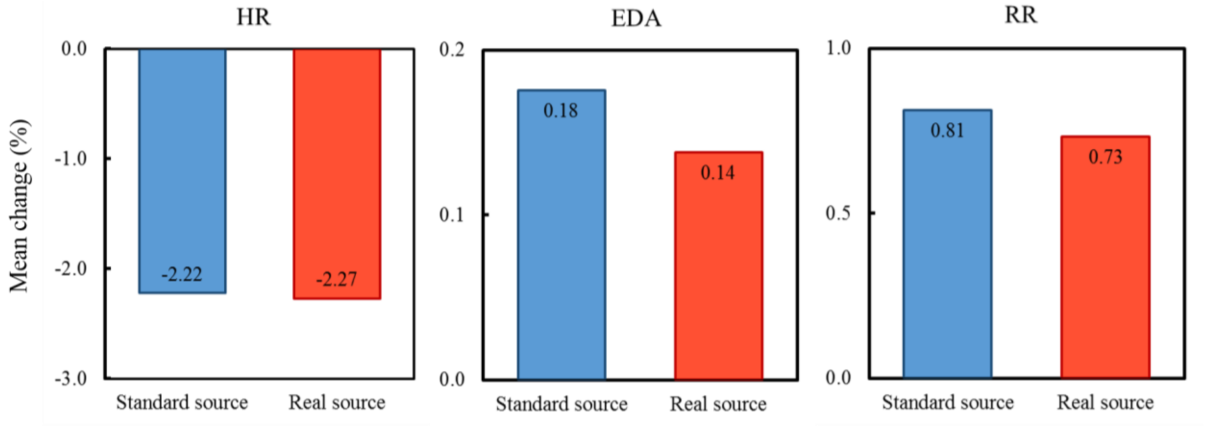


Figure 4. Mean percentage changes of physiological responses across types of noise sources (standard or real impact sources).

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.

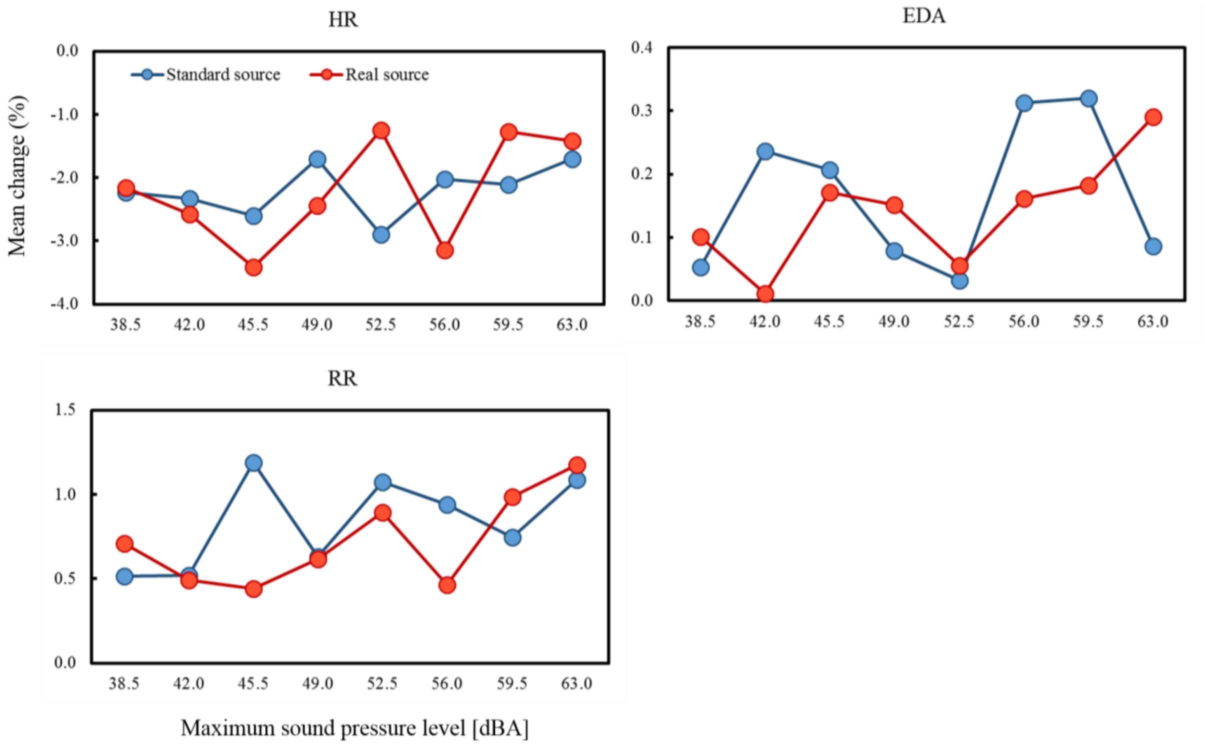


Figure 5. Physiological responses as a function of L_{AFmax} across types of noise sources (standard or real impact sources).

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.

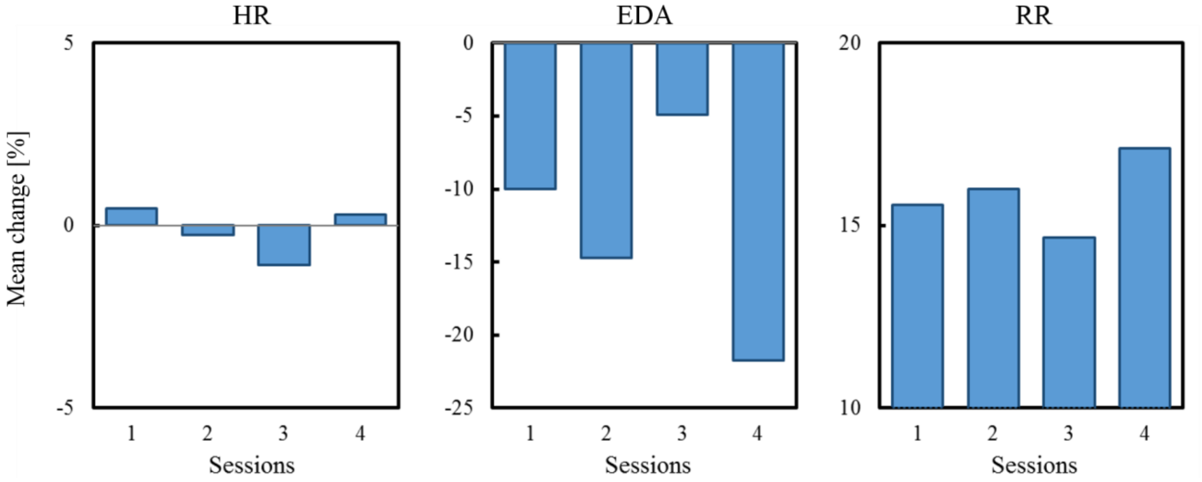


Figure 6. Physiological responses for Sessions 1-4.

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.

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