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INFLUENCE OF NOISE SENSITIVITY ON PHYSIOLOGICAL RESPONSES TO FLOOR IMPACT SOUNDS

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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 ($L_{Aeq,5min}$). 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 ($L_{Aeq,5min}$). Compared to the road traffic noise, two floor impact noises had dominant sound pressure levels at low frequencies below 125 Hz.

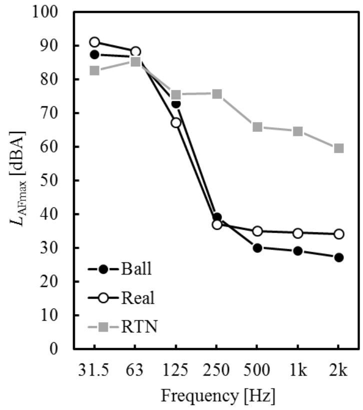

Figure 1: Frequency characteristics of the three types of stimuli.

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 ($L_{Aeq,5min}$) 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 ($L_{Aeq,5min}$) was greater than all other stimuli, annoyance rating for this stimulus was found to be the biggest.

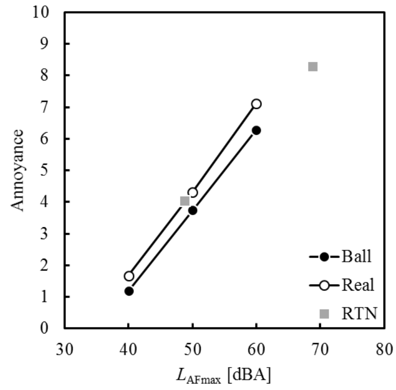

Figure 2: Mean annoyance to difference noise sources at all noise levels.

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.

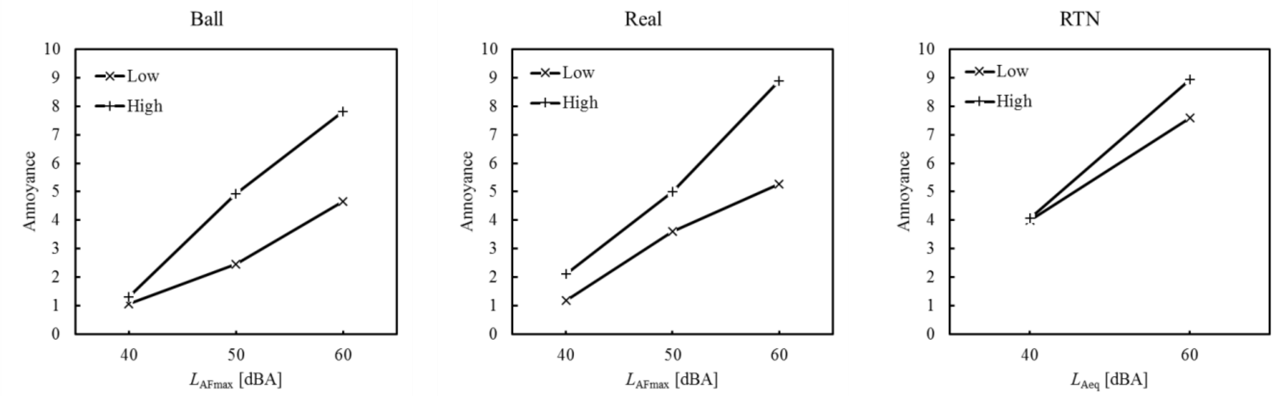

Figure 3: Mean annoyance of the two noise-sensitivity groups to difference noise sources at all noise levels.

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.

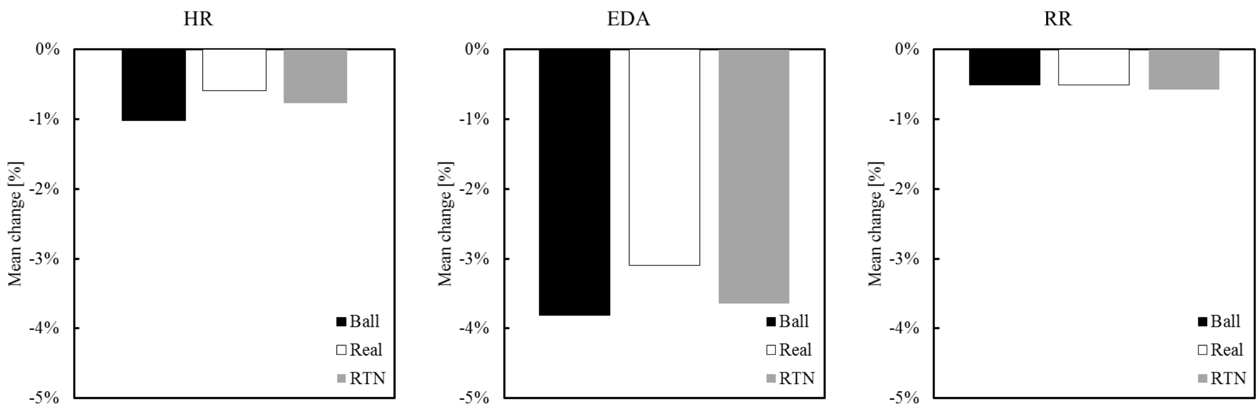

Figure 4: Mean physiological changes to difference noise sources.

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}).

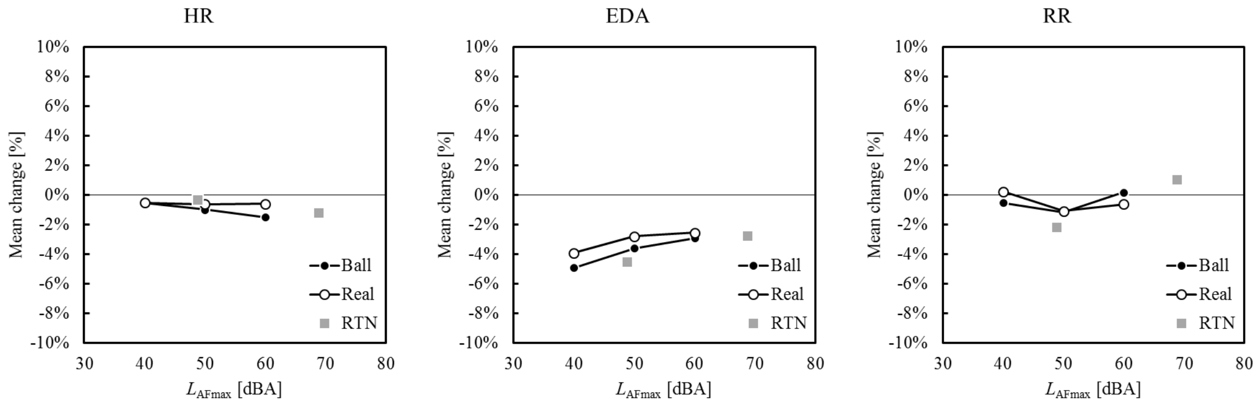

Figure 5: Mean physiological changes to difference noise sources at different noise levels.

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.

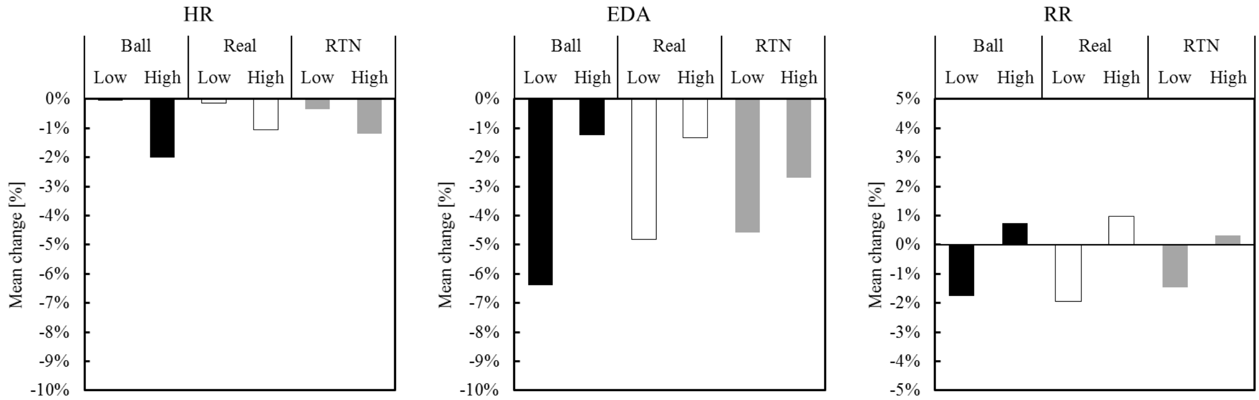

Figure 6: Mean physiological changes of the two noise-sensitivity groups to difference noise sources.

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).

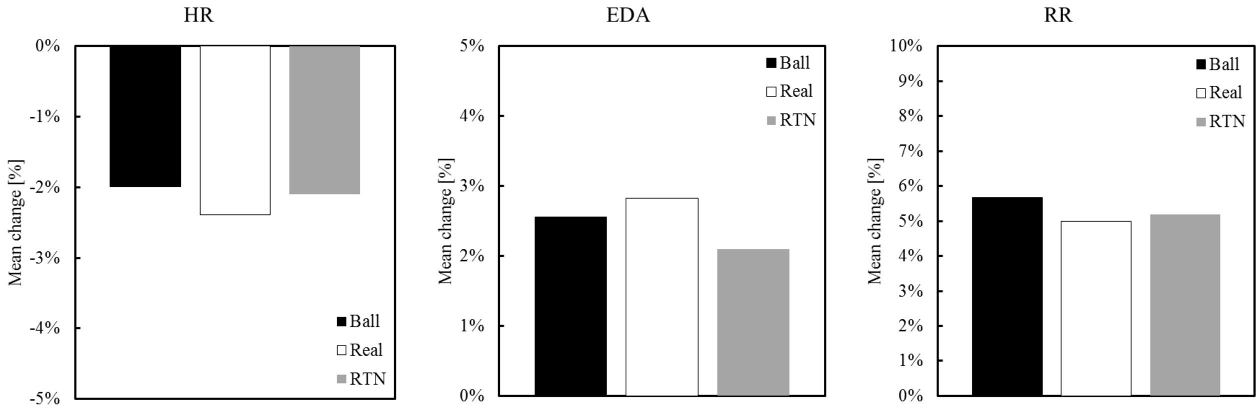

Figure 7: Mean physiological changes to difference noise sources at 30-second noise exposure.

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.

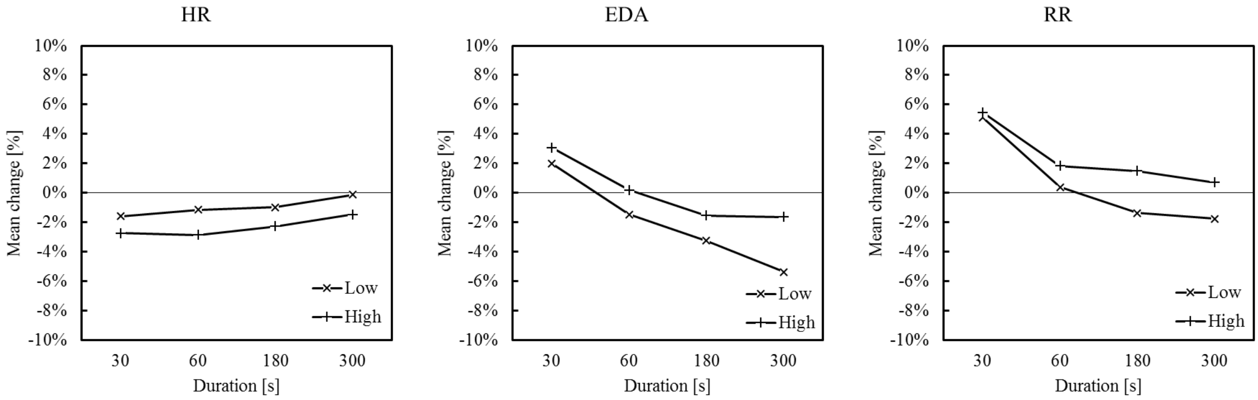

Figure 8: Mean physiological changes of the two noise-sensitivity groups at different durations.

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.

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