Emotions elicited by indoor sound sources in wooden residential buildings

Frescura Alessia[1]

Pyoung-Jik Lee[2]

Acoustic Research Unit, School of Architecture, University of Liverpool

ABSTRACT

In the present study, the emotional reactions to commonly occurring neighbour's sounds in wooden dwellings were investigated. Listening tests were performed to assess the relationship between affective ratings and physiological parameters in distinct acoustics scenarios. Experimental work was carried out in an audiometric booth with a low background noise level. A series of impact and airborne sounds were presented through headphones and subwoofer, while the picture of a living room was shown on a monitor. The impact sound sources were an adult walking and a child running recorded in a laboratory equipped with several floor configurations. Two airborne sounds were selected, a lively conversation and a piece of classical piano music, and digitally filtered to resemble good, medium and poor sound insulation performances of vertical partitions. The experiment consisted of two sessions: in the first session, the sound sources were presented individually, while in the second one, pairs of impact and airborne sources were presented. In both sessions, affective ratings were assessed using a nine-point SAM (Self-Assessment Manikin) scale for arousal and valence. In addition, facial electromyography (f-EMG) was monitored throughout the experiment. Findings showed that increasing sound pressure level of footsteps and conversations caused an increase of arousal and a decrease of valence. Furthermore, affective ratings indicated that neighbour sounds activated the defensive motivational circuit which mediates the reactions to threat. It was observed that activity in the Corrugator Supercilii muscle group increased and activity in the Zygomaticus Major muscle group decreased when listening to impact and airborne sounds.

1. INTRODUCTION

Emotions are central to the life regulating processes of living creatures [1-3]. They can be regarded as bio regulatory reactions that aim at promoting, directly or indirectly, the sort of physiological states that secure not just survival, but survival regulated into the range that is identified with well-being [4]. These reactions subsequently trigger other responses including complex socially oriented ones that involve specific facial expressions [5-7]. Emotional competent stimuli causing chemical and neural responses surround us every day and may involve all of our senses. With regard to acoustic stimuli, a wide body of research investigating emotional reactions evoked by music exists [8-11]. However, few studies have been focusing on the emotional impact of everyday life sounds.

The majority of previous studies referred to the urban soundscape and examined how the role of emotions can help in defining the perception of sound quality [12-14]. Others in the environmental noise field also investigated emotions elicited by noise caused by road traffic and construction sites [15, 16]. Indoor soundscape was rarely taken into account even though indoor noise such as noise from a neighbour is a common cause of annoyance and its effect is a major source of emotional responses in urban environments [17-21]. Furthermore, the growing demands for sustainable buildings promoting lightweight constructions and the use of raw and locally sourced material such as wood, generated new living scenarios and indoor soundscapes which need to be investigated. Wooden residential buildings, in fact, are poorer in impact and airborne sound insulation performances than heavyweight buildings; thus, sustainable construction trend might lead to uncomfortable acoustics conditions for dwellers.

Several studies have examined the emotional reactions to footstep sounds in buildings. Recently, Park et al. used lexicon to investigate the emotions evoked by footsteps noise in residential buildings, showing how these are significantly affected by noise levels and how noise sensitivity and attitude toward neighbour moderated emotional responses [22]. The emotional responses to various types of stimuli have been frequently assessed by using the Self-Assessment Manikin (SAM) [23, 24]. A series of studies have adopted the SAM to investigate affective reactions to acoustic stimuli. Affective reactions to acoustic stimuli were firstly assessed to identify emotional reactions to naturally occurring sounds such as screams and a bird singing [25]. Tajadura-Jiménez et al. then highlighted how auditory stimuli are capable of inducing emotional reactions and how these do not depend solely on the physical properties of the sounds but also on the meaning ascribed to it by the listener [26]. Furthermore, the investigation of emotional impact of sounds showed to be adequate in understanding the embodied auditory perception, underlying how unpleasant sounds can evoke more intense emotional responses when compared to neural or pleasant ones [27]. As the emotional states emerging during exposure to auditory stimuli may be registered by means of facial reactions [28, 29], in this research the acquisition of facial electromyography (f-EMG) was also included. More specifically, the activity in the Zygomaticus Major Muscle and Corrugator Supercilii muscles groups was recorded as is been shown that positive stimuli evoke increased zygomatic activity (smiling), whereas negative emotional stimuli spontaneously elicit increased Corrugator muscle activity (frowning) [30-32]. The assessment of noise sensitivity was also included by using a 35-items questionnaire developed by Schutte et al. [33] as this trait is been shown to influence the subjective experience of unwanted sounds in our homes [34-36].

2. METHODOLOGY

2.1 Participants

Participants were recruited after the study was ethically approved by the School of the Arts Committee on Research Ethics, University of Liverpool. Forty-one adults with self-reported normal hearing took part in the experiment. The participants aged between 20 and 40 (median= 28 and std=4.4).

2.2 Experimental design

The experiment took place in an audiometric booth with a low background noise level. Participants were sitting on a chair and asked to answer the questionnaire on a monitor. The stimuli were presented through headphones (DT 770 Pro) and a subwoofer (SONAB System 9 CSW-71000) which was placed in front of the participants. Sound above 63 Hz was presented via the headphones, while low-frequency sounds below 63 Hz were presented via the subwoofer. White noise (NC 25) was presented through headphones throughout the experiment as ambient noise in the living room. The experiment was composed of four sessions (i.e. three combined sounds sessions and one single sound session). There were breaks between sessions to avoid excessive fatigue and loss of concentration. In the single sound session, each of the impact and airborne noise sources was presented for 15 minutes, while in the remaining sessions, the impact noise combined with airborne noise sources were presented for 21 minutes each. All sound sources and sessions were randomised across participants to avoid order effects. Each session consisted of the repetition of the following 40 s sequence: 10 s of baseline with a presentation of the black screen; 20 s of sound stimulus (single or combined sources) together with a picture of a living room on the screen; the final 10 s for answering questions on the monitor. During the experiments, participants were asked to imagine being relaxing in their own homes. Before the starting of the listening test, noise sensitivity was assessed using NoiSeQ questionnaire [33].

2.3 Sound stimuli

The sound stimuli were both impact and airborne sounds which are commonly heard from neighboring units in wooden residential dwellings. The impact sound sources were recorded in a laboratory equipped with different wooden floor configurations at the University of Applied Science of Rosenheim. The different floor configurations were a timber joist slab with a chipboard panel on top (i.e. basic floor) with and without a floating floor, a suspended ceiling, and the two solutions installed together. All the configurations were also altered by adding or removing a carpet tiles finish. The recordings were made using a binaural head representing a person sitting on a sofa in the receiving room. The impact sources were two different kind of footsteps: an adult walking (1.65m, 50 kg) and a child running (1.12m, 22 kg and 1.05m, 17 kg). Both the adult and children wore socks during the recordings. Sound pressure levels (L_{AFmax}) of the adult walking with two different speeds (‘normal’ at 1.8 Hz and ‘fast’ at 2.2 Hz) ranged from 30 to 55 dB across the floor configurations. The child running recordings showed a narrower variation of noise level between 35 and 50 dB (L_{AFmax}). All the sound stimuli chosen for the listening tests showed slightly different frequency characteristics as they were recorded from different configurations. The airborne sources were a lively conversation and a piece of classical piano music. Both clips were digitally filtered using Adobe Audition to resemble lightweight partitions with different sound insulation performances (R_w=52, 43, and 33 dB). For the simulated partition with R_w=52 dB, the noise levels (L_{Aeq}) were 24 dB and 25 dB, respectively for conversation and music. The levels of them were 29 dB for the partition resembled an average performance (R_w=43 dB) for both clips, while, for the poor partitions with R_w=33 dB, the levels were 42 dB and 44 dB, respectively for conversation and music. The frequency characteristics of all the sound stimuli are presented in [37].

2.4 Emotions appraisal through Self-Assessment Manikin (SAM)

The nine-point Self-Assessment Manikin (SAM) scale was used in the current study to directly measure emotional response elicited by the sound stimuli in terms of arousal and valence. As shown in Fig. 1, the arousal scale ranges from a calm figure to an excited one, while the valence scale shows SAM smiling at right end and unhappiness at the other. Before the listening test, participants were invited to familiarise with the use of the SAM pictographic scales through a short explanation and a training session of approximately five minutes.

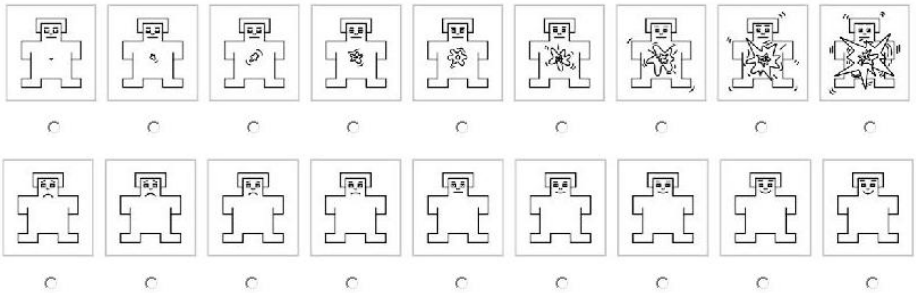

Figure 1 Self-assessment manikin (SAM) scales used for assessment of arousal (top scale) and valence (second scale).

2.5 Facial EMG measurement

To investigate physiological responses to the sound stimuli, f-EMG activities in the Corrugator Supercilii and Zygomaticus Major muscle groups were monitored throughout the experiment with four mm standard silver/silver chloride electrodes. Sensors were placed on the left side of the face as the right brain hemisphere is predominantly involved in spontaneous emotional reactions (contralateral motor control) [38]. In order to improve the quality of the f-EMG signals, the participant's skin was prepared using a gentle rubbing skin preparation gel in the areas where the sensors were placed. The impedance level of the skin was examined to be low enough for the signals collection (< 5kΩ) before the start of each listening test. The signals were acquired and transmitted through a shielded cable to Biopac amplifiers (Biopac Systems, Inc., Santa Barbara, CA), where signals were amplified 5,000×. Signals were digitised at 1000 Hz, then recorded and displayed on a laboratory computer using AcqKnowledge software interface. Data were then visually inspected offline to detect artifacts and subjected to a square-root transformation. EMG reactivity was measured as the mean percentage change between activity during the 6 s stimulus period and the 1 s immediately before stimulus presentation [39].

3. RESULTS AND DISCUSSIONS

3.1 Affective ratings

Fig. 2 a shows the affective ratings of the single sounds in a two-dimensional space defined by arousal and valence. The grey colour represents the ratings of the adult walking at normal and fast pace with a range of L_{AFmax} from 30 to 55 dB. The affective ratings were not significantly influenced by the pace of the walker. The sound pressure level instead greatly affected the affective judgments. The arousal ratings were between 1.95 ± 1.01 and 3.20 ± 1.85 on the nine-scale for the footsteps recorded from the floors with good sound insulation performance by installing a floating floor and suspended ceiling (L_{AFmax}=30-35 dB). The ratings then increased up to 7.08 ± 1.97 when the footsteps were recorded through the basic structure with L_{AFmax}=55 dB. Similarly, the valence assessments were influenced by the sound pressure level of the footsteps: for 30-35 dB, the ratings were between 5.51 ± 1.34 and 4.40 ± 1.63 (neutral) and for 55 dB, the ratings were of 1.93 ± 1.05 (unhappy). Similar results were found from the affective reactions to child running with a shorter range of noise level. The arousal and valence ratings significantly increased and decreased, respectively with the increase of the sound pressure level. The ratings of the airborne sources (conversation and music) presented two different tendencies across their sound pressure levels and thus, across the sound insulation performance of the vertical partitions. For the conversation through different partitions, the arousal increased from 2.37 ± 1.43 to 5.51 ± 1.93 and the valence decreased from 5.24 ± 1.43 to 3.00 ± 1.48 , while the sound pressure level (L_{Aeq}) changed from 24 dB to 42 dB. The results imply that the perceived speech intelligibility of the conversation clip may affect the affective judgments. However, the average ratings of the music clip were not much changed with a variation of sound pressure level even though the standard deviations increased, especially for arousal judgments. The arousal ratings were between 2.22 ± 6.07 and 3.07 ± 5.28, while the valence ratings also showed a limited change, varying from 5.28 ± 2.06 and 6.08 ± 1.54. This may be because the music clip (i.e. a classical piano piece) was quite pleasant to participants. Therefore, this result does not represent the affective reactions to the vast variety of music which could be annoying to the residents living in a lightweight residential building. The previous study also reported that annoyance of different music sounds (rap, house or pop) transmitted from vertical partitions with different sound insulation performances greatly varied [40].

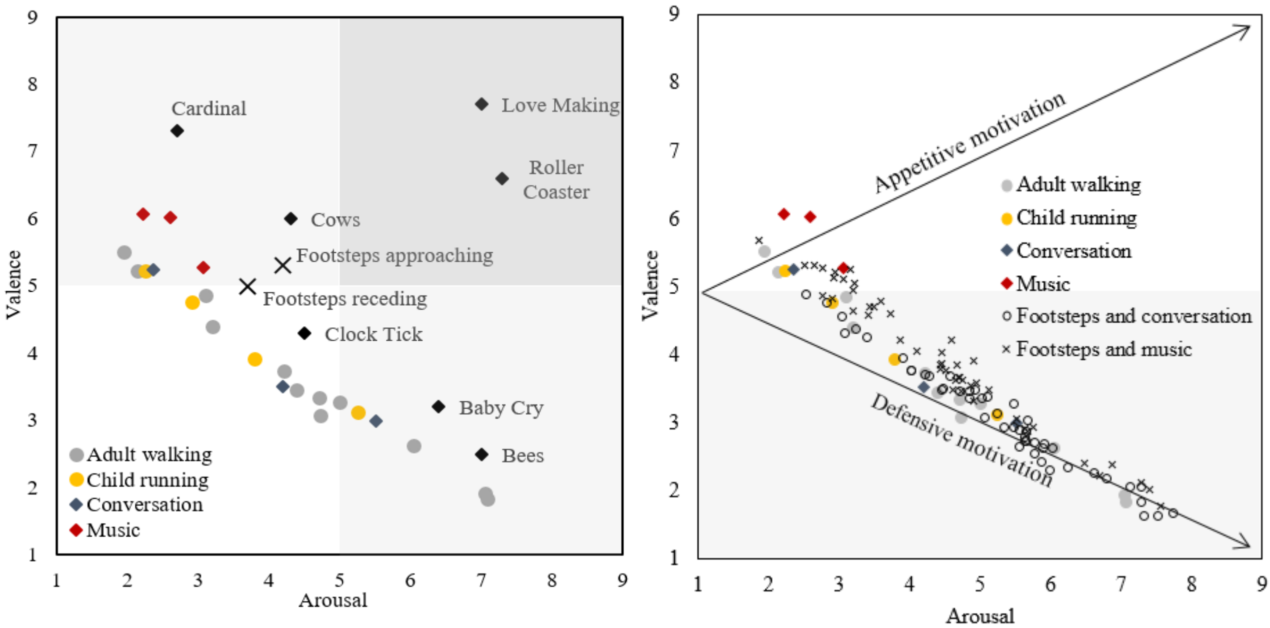

Figure 2 a) Affective ratings of the sound stimuli. The ratings in black represent the affective ratings of natural occurring sounds [25] and footsteps approaching and receding [27]; b) Affective ratings of the single and combined noise sources with appetitive and defensive motivational circuits.

Fig. 2 a also showed the affective ratings of different sounds reported in previous studies; naturally occurring sounds such as the ones from bird singing, roller coaster, tick of the clock, and baby crying [25] and footsteps approaching and receding [27]. In terms of arousal, most footstep sounds used in the present study were less exciting than a roller coaster and baby cry sounds.

However, with the increasing of the sound pressure level, the arousal ratings became comparable to those of the cardinal singing at 30-35 dB, the clock tick at 40-45 dB, and the roller coaster sound at 55 dB. Similarly, the valence ratings varied with the sound pressure level; the ratings were similar to the natural sound from cows at 30 dB and the ratings at 50 dB corresponded to the rating of a baby crying. The valence ratings of the footsteps approaching and receding presented with an intensity ramp passing from 68 to 86 dB (L_{Aeq}) [27] were similar to those of the adult walking at 35-40 dB in the present study (L_{AFmax}). It is remarkable to notice that the "Walking" sound has normative valence and arousal ratings of 4.15 ± 1.28 and 5.43 ± 1.9, respectively and is classified as neutral in the International Affective Digitalised Sounds (IADS) [41]. However, the walking sounds above mentioned were not from neighbouring units but presented as if happening in the same space where the listener was; thus, those sounds are difficoult to compare with the footstep sounds of the current study. In the future, more different types of sounds such as dropping of objects, moving of furniture, and appliances would be helpful to extend the affective ratings of neighbor noise in residential buildings.

Fig. 2 b presents the affective ratings of the sound sources heard singularly or in combinations between footstep and airborne sounds with indication of appetitive and defensive motivation circuits. It was proposed that two overlapping neural circuits have evolved in the brain of complex animals: the appetitive motivation organises response to stimuli promoting survival (e.g., food), while the defensive motivation mediates reaction to threat (e.g., natural disaster) [42]. The ratings of the floor impact noise and conversation mostly overlap with the defensive motivation circuit. This indicates that those sounds activate the defensive motivational circuit which mediates reactions to threat. On the other hand, the music clips activated the appetitive motivation circuit.

3.2 Effects of noise sensitivity on affective ratings

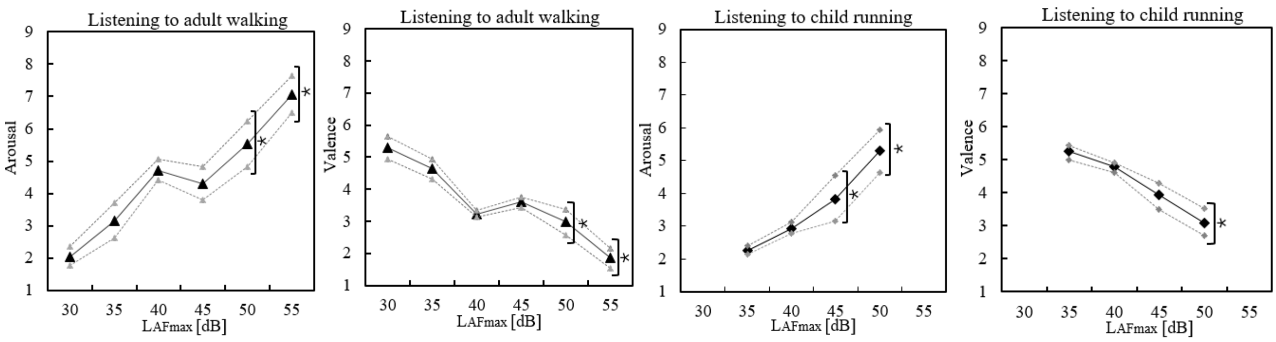

Figure 3 arousal and valence ratings of adult walking and child running across the low and high noise sensitive groups ($p<0.05$).*

The self-reported noise sensitivity of the participants ranged from 28 up to 76 (median=58 and std=11.4). The participants whose scores were below the median value were classified into the low noise sensitivity group, while those with the score above the median value were identified as the high noise sensitivity group. Fig. 3 shows the affective ratings of the single footstep sounds across the low and high noise sensitivity groups. Overall, the difference between the two clusters becomes more significant when the sound pressure level in the receiving room is above 45-50 dB, corresponding to the basic floor with or without a 5mm carpet finish. In contrast, the influence of the noise sensitivity on the affective ratings was not significant when the noise levels are less than 45 dB with a floating floor or a suspended ceiling. The significance of the differences between high and low noise sensitive groups was compared using t-tests. For the adult walking, both arousal and valence ratings were significantly different for the two groups at 50 and 55 dB ($p<0.05$). For the child running, two significant differences in the arousal were found at 45 and 50 dB ($p<0.05$), while the valence had one significant difference at 50 dB. Similarly, the differences between the high and low noise sensitive groups tended to significant above 50 dB for the footstep sounds combined with conversation or music. However, no significant difference was found in the arousal and valence ratings of the airborne sources despite their variation in sound pressure level.

3.3 f-EMG responses

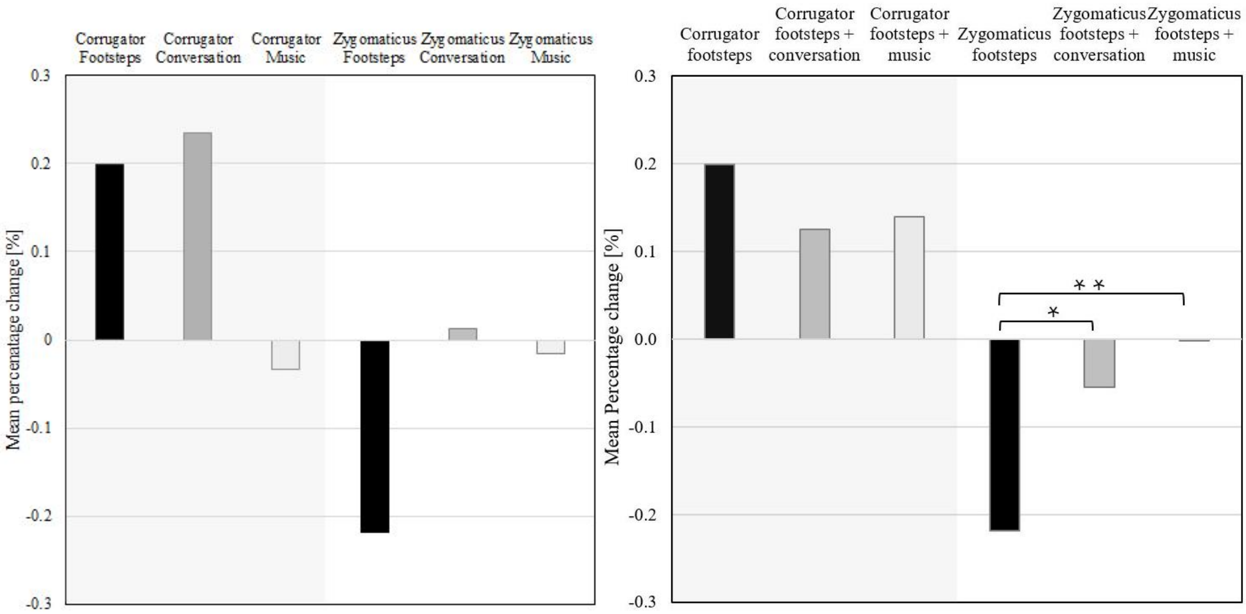

*Figure 4 a) f-EMG responses of Corrugator Supercilii and Zygomaticus Major muscle groups to footsteps, conversation and music; b) f-EMG responses of Corrugator Supercilii and Zygomaticus Major muscle groups to single and combined sound sources (*p<0.05, **p<0.01).*

Fig. 4 a shows the mean percentage changes of activity in the Corrugator Supercilii and Zygomaticus major muscle groups in response to single footstep and airborne sound sources. On average, Corrugator activity increased and Zygomaticus activity decreased for both impact and airborne sounds. Specifically, listening to footsteps sounds (adult walking and child running) and conversation increased the Corrugator activity by 0.2% and 0.22%, respectively. Increased activity in the Corrugator muscle is generally caused by unpleasant and negative stimuli [38]. The results of the Corrugator validate the hypothesis that footsteps sounds may generate negative emotional reactions. However, an increased Corrugator response does not necessarily reflect a negative emotional response, because the Corrugator muscle is active not only in emotional expressions such as fear, anger, and sadness but even in non-emotional gestures. Thus, activity in the Corrugator muscle could be connected to lowering or rising of the brows, with the biological function of decrease or increase the visual input [43]. In the future, including further recordings from several muscle regions would be helpful to interpret the change of Corrugator muscle more specifically. As presented in fig. 4 a, the activity in the Zygomaticus major muscle group decreased by 0.22% for the footstep sounds, whereas hearing conversation and music did not lead a significant change in Zygomaticus major muscle. On average, footstep sounds generated larger changes than airborne sounds; however, the differences in the activity of the two muscle groups were not statistically significant and great variation was found between the two different airborne sources presented.

The responses to the combined sound sources are presented in fig. 4 b with the responses to single footstep sounds as a reference. The responses to the combined noise sources were similar to those of the single sounds by showing increasing Corrugator muscle and decreasing Zygomaticus Major muscle. More specifically, listening to the footstep sounds in combinations with conversation or music led to increases of Corrugator muscle activity by 0.12% and 0.14%, respectively. These changes were slightly lower than the change after exposure to the footstep sounds alone. However, the differences in the activity of the Corrugator between the single and combined noise sources were not statistically different. Similarly, adding airborne sources to the footstep sounds reduced the changes in the Zygomaticus Major muscle activity. Statistical analysis shows that those changes were significantly different for adding conversation ($p<0.05$) and music ($p<0.01$). This may suggest that the single presence of footstep sounds causes the largest activation of the Corrugator and the largest de-activation of the Zygomaticus. Besides, the addition of airborne sources to footstep sounds seems to reduce the reactions in both the facial muscle groups.

3.4 Effect of noise sensitivity on f-EMG responses

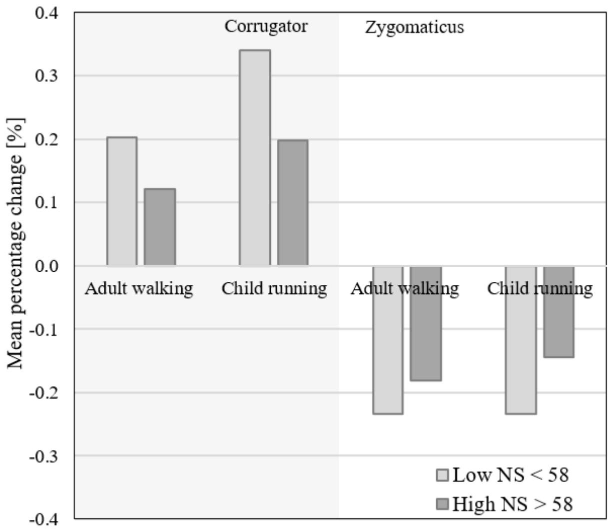

Figure 5 Influence of noise sensitivity on f-EMG responses listening to footsteps for Corrugator and Zygomaticus muscle groups.

The effect of noise sensitivity on the changes in Corrugator and Zygomaticus muscles are shown in Fig. 5. The responses of the low noise sensitivity group were consistently larger than those of the high noise sensitivity group for both the adult walking and the child running. However, no statistically significant difference was found in f-EMG responses between two sensitivity groups. Similar results were obtained also with the responses of the conversation and music clips, indicating insignificant differences between the noise sensitivity groups.

4. CONCLUSIONS

The present study measured the participants' affective ratings to single and combined sound sources commonly heard in wooden residential dwellings in terms of arousal and valence. The participants' f-EMG responses to sound stimuli were also monitored. It was found that listening to footsteps and conversation caused an increase in arousal and a decrease in valence as the sound pressure level increased. It was also observed that neighbour sounds activated the defensive motivational circuit underlying emotional expression mediating reactions to threat. The differences in affective ratings between the high and low noise sensitivity groups were statistically significant when the participants were exposed to the footstep sound transmitted through a poor performing floor (i.e, 50-55 dB in terms of L_{AFmax}). The activities in the Corrugator Supercilii muscle group the Zygomaticus Major Muscle group increased and decreased, respectively after the exposures to impact and airborne sources from neighbors. A statistically significant difference in the activation of the Zygomaticus was found between single footstep sound and combined sound sources. Moreover, the low-noise sensitivity group showed larger changes in both muscle groups than the high-noise sensitivity group; but the differences between them were not statistically significant.

5. AKNOWLEDGEMENTS

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 721536.

6. REFERENCES

[1] A.R. Damasio, T.J. Grabowski, A. Bechara, H. Damasio, L.L.B. Ponto, J. Parvizi, R.D. Hichwa: *"Subcortical and cortical brain activity during the feeling of self-generated emotions"*, Nature Neuroscience, Vol. 3, No. 10, pp. 1049-1056, 2000.

[2] D.A. Denton, M.J. McKinley, M. Farrell, G.F. Egan: *" The role of primordial emotions in the evolutionary origin of consciousness"*, Consciousness and Cognition, Vol. 18, No. 2, pp. 500-514, 2009.

[3] A.R. Damasio: *The feeling of what happens: Body and emotion in the making of consciousness*, Houghton Mifflin Harcourt, 1999.

[4] A.S.R. Manstead, N. Frijda, A. Fischer: *Feelings and Emotions: The Amsterdam Symposium*, Cambridge University Press, Cambridge, 2004.

[5] P. Eckman: "Universal and cultural differences in facial expression of emotion", *Nebraska symposium on motivation*, pp. 207-284, 1972.

[6] R.J. Davidson, P. Ekman, C.D. Saron, J.A. Senulis, W.V. Friesen: *"Approach-withdrawal and cerebral asymmetry: emotional expression and brain physiology: I"* , Journal of personality and social psychology, Vol. 58, No. 2, p. 330, 1990.

[7] J.T. Cacioppo, G.G. Berntson, J.T. Larsen, K.M. Poehlmann, T.A. Ito: *The psychophysiology of emotion, Handbook of emotions 2*, Guilford press, New York, 2000.

[8] J.A. Sloboda, S.A. O'Neill, A. Ivaldi: *"Functions of Music in Everyday Life: An Exploratory Study Using the Experience Sampling Method"*, Musicae Scientiae, Vol. 5, No. 1, pp. 9-32, 2001.

[9] M. Zentner, D. Grandjean, K.R. Scherer: *"Emotions evoked by the sound of music: Characterization, classification, and measurement"*, Emotion, Vol. 8, No. 4, pp. 494-521, 2004.

[10] P.N. Juslin, S. Liljeström, D. Västfjäll, L.-O. Lundqvist: *How does music evoke emotions? Exploring the underlying mechanisms, Handbook of music and emotion: Theory, research, applications*, Oxford University Press, New York, 2010.

[11] S. Koelsch: *"Music‐evoked emotions: principles, brain correlates, and implications for therapy"*, Annals of the New York Academy of Sciences, Vol. 1337, No. 1, pp. 193-201, 2015.

[12] M. Qiu, J. Zhang, C. Zheng: *"Exploring tourists' soundscape emotion and its impact on sustainable tourism development"*, Asia Pacific Journal of Tourism Research, Vol. 23, No. 9, pp. 862-879, 2018.
[13] A. Irwin, D.A. Hall, A. Peters, C.J. Plack: *"Listening to urban soundscapes: Physiological validity of perceptual dimensions"*, Psychophysiology, Vol. 48, No. 2, pp. 258-268, 2011.
[14] D. Dubois, C. Guastavino, M. Raimbault: *"A cognitive approach to urban soundscapes: Using verbal data to access everyday life auditory categories"*, Acta acustica united with acustica, Vol. 92, No. 6, pp. 865-874, 2006.
[15] P. Gomez, B. Danuser: *"Affective and physiological responses to environmental noises and music"*, International Journal of psychophysiology, Vol. 53, No. 2, pp. 91-103, 2004.
[16] K. Hume, M. Ahtamad: *"Physiological responses to and subjective estimates of soundscape elements"*, Applied Acoustics, Vol. 74, No. 2, pp. 275-281, 2013.
[17] C. Maschke, H. Niemann: *"Health effects of annoyance induced by neighbour noise"*, Noise Control Engineering Journal, Vol. 55, No. 3, pp. 348-356, 2007.
[18] C. Grimwood: *"Complaints about poor sound insulation between dwellings in england and wales"*, Applied Acoustics, Vol. 52, No. 3, pp. 211-223, 1997.
[19] S.H. Park, P.J. Lee, B.K. Lee: *"Levels and sources of neighbour noise in heavyweight residential buildings in Korea"*, Applied Acoustics, Vol. 120, pp. 148-157, 2017.
[20] S.H. Park, P.J. Lee: *"Effects of floor impact noise on psychophysiological responses"*, Building and Environment, Vol. 116, pp.173-181, 2017.
[21] S. Stansfeld, M. Haines, B. Brown: *"Noise and health in the urban environment"*, Reviews on environmental health, Vol. 15, No. 1/2, pp. 43-82, 2000.
[22] S.H. Park, P.J. Lee, J.H. Jeong: *"Emotions evoked by exposure to footstep noise in residential buildings"*, PLOS ONE, Vol. 13, no. 8, 2018.
[23] P. Lang: *"Behavioral treatment and bio-behavioral assessment : computer applications"*, Technology in mental health care delivery systems, pp. 119-137, 1980.
[24] M.M. Bradley, P.J. Lang: *"Measuring emotion: the self-assessment manikin and the semantic differential"*, Journal of behavior therapy and experimental psychiatry Vol. 25, No. 1, pp. 49-59, 1994.
[25] M.M. Bradley, P.J. Lang: *"Affective reactions to acoustic stimuli"*, Psychophysiology, Vol. 37, No. 2, pp. 204-215, 2000.
[26] E. Asutay, D. Västfjäll, A. Tajadura-Jiménez, A. Genell, P. Bergman, M. Kleiner: *"Emoacoustics: A study of the psychoacoustical and psychological dimensions of emotional sound design"*, Journal of the Audio Engineering Society, Vol. 60, No.1/2, pp. 21-28, 2012.
[27] A. Tajadura-Jiménez, A. Väljamäe, E. Asutay, D. Västfjäll: *"Embodied auditory perception: The emotional impact of approaching and receding sound sources"*, Emotion, Vol. 10, No. 2, pp. 216-229, 2010.
[28] L. Jäncke, J. Vogt, F. Musial, K. Lutz, K.T. Kalveram: *"Facial EMG responses to auditory stimuli"*, International Journal of Psychophysiology, Vol. 22, No. 1, pp. 85-96, 1996.
[29] U. Dimberg: "*Facial electromyographic reactions and autonomic activity to auditory stimuli"*, Biological Psychology, Vol. 31, No. 2, pp. 137-147, 1990.
[30] U. Dimberg: *"Facial Reactions to Facial Expressions"* , Psychophysiology, Vol. 19, No. 6, pp. 643-647, 1982.
[31] U. Dimberg: *"Facial reactions to fear-relevant and fear-irrelevant stimuli"*, Biological psychology, Vol. 23, No. 2, pp.153-161, 1986.

[32] U. Dimberg, S. Thell: *"Facial electromyography, fear relevance and the experience of stimuli"*, Journal of Psychophysiology, Vol. 2, No. 3, pp. 213-219, 1988.
[33] M. Schutte, A. Marks, E. Wenning, B. Griefahn: *"The development of the noise sensitivity questionnaire"*, Noise and Health, Vol. 9, No. 34, pp. 15-24, 2007.
[34] J.K. Ryu, J.Y. Jeon: *"Influence of noise sensitivity on annoyance of indoor and outdoor noises in residential buildings"*, Applied Acoustics, Vol. 72, No. 6, pp. 336-340, 2011.
[35] A. Marks, B. Griefahn: *"Associations between noise sensitivity and sleep, subjectively evaluated sleep quality, annoyance, and performance after exposure to nocturnal traffic noise"*, Noise and Health, Vol. 9, No. 34, pp. 1-7, 2007.
[36] S.H. Park, P.J. Lee, J.H. Jeong: *"Effects of noise sensitivity on psychophysiological responses to building noise"*, Building and Environment, Vol. 136, pp. 302-311, 2018.
[37] A. Frescura, P.J. Lee: "Perception of combined indoor noise sources in lightweight buildings", *Proceedings of ICA 2019*, pp. 5140-5146.
[38] J.L. Andreassi: *Psychophysiology: Human behavior and physiological response*, Psychology Press, 2010.
[39] P.J. Lang, M.K. Greenwald, M.M. Bradley, A.O. Hamm: *"Looking at pictures: Affective, facial, visceral, and behavioral reactions"*, Psychophysiology, Vol. 30, No. 3, pp. 261-273, 1993.
[40] H.K. Park, J.S. Bradley: *"Evaluating standard airborne sound insulation measures in terms of annoyance, loudness, and audibility ratings"*, The Journal of the Acoustical Society of America, Vol. 126, No. 1, pp. 208-219, 2009.
[41] M.M. Bradley, P.J. Lang: *International affective digitalised sounds: affective ratings of sounds and instruction manual*, Gainesville, FL: University of Florida, NIMH Centre for the study of emotions and attention, 2007.
[42] A.J. Elliot: *Handbook of approach and avoidance motivation*, Psychology Press, 2013.
[43] P. Ekman: *Emotional and conversational nonverbal signals, Language, knowledge, and representation*, Springer, 2004.