Effect of neighbours sounds in wooden residential buildings on restorative EEG rhythm (Alpha waves)

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ABSTRACT

The present study aimed to explore the effect of neighbours sounds, which are commonly heard in wooden residential buildings, on restorative EEG rhythm represented by Alpha waves (α-EEG). Thirty participants took part in a listening test which was performed to collect EEG data in distinct acoustics scenarios. Noise sensitivity and attitude towards neighbours were introduced as non-acoustic moderators and assessed through questionnaires before the start of the experiment. A series of impact and airborne sounds were presented through loudspeakers and a subwoofer, while participants sat comfortably in the simulated living room wearing the EEG headset (B-alert X24® system). The impact sound sources were footsteps from an adult walking recorded in a laboratory on different floor configurations and thus, varying in sound pressure levels and frequency characteristics. The airborne sound sources were a lively conversation and a piece of classical piano music, digitally filtered to represent good and poor sound insulation performances of vertical partitions. The effects of sound stimuli and non-acoustic factors on α-EEG (8-13 Hz) were then analysed. Differences in response to distinct acoustic scenarios were observed. Additionally, α-EEG was affected by noise sensitivity and attitude towards neighbours.

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1. INTRODUCTION

Sound from neighbours is a key locus of contestation in densifying cities where the construction of high-rise lightweight buildings is promoted as more sustainable for the environment. Neighbours' sounds invade indoor residential spaces and impair their restorative potential, impacting the occupants' lives in meaningful ways, causing stress, and reducing the quality of well-being at home [1-3]. Particularly, Bard et al. [4] reported that residents in timber buildings are still exposed to various noises from their neighbours including floor impact noise. Impact sounds generated by footsteps from upstairs neighbours are considered among the most annoying sounds commonly heard in residential buildings [5, 6]. Additionally, speech and music have been reported among the most frequently heard airborne sound sources from neighbouring units [7-9]. Neighbours sounds are acousmatic, as residents do not have direct visual access to the sound source. In theatre and movies, acousmatic sounds are commonly used to attract the audience's attention by making them wonder what is generating the sound [10]. This could be accentuated when residents are relaxing in their homes, as low-intensity activity (i.e., not being busy) makes people more sensitive to the acoustic environment, especially when noise is generated by human activity [11]. Despite being a very common issue, sounds from neighbours have not been investigated and only very few studies exist on the physiological responses to neighbours sounds [12, 13].

The electroencephalogram (EEG) is defined as the electrical activity of an alternating type recorded from the scalp surface after being picked up by metal electrodes and conductive media [14]. Among the several options available for measuring physiological reactions to auditory stimuli, EEG recording has been made possible by contemporary technologies in a relatively easy way using portable devices. These offer the precious opportunity of acquiring data directly from the scalp, where brain activity is detectable almost instantaneously in synchrony with the stimulus presentation [15, 16]. From EEG responses, several EEG rhythms bands can be obtained such as Delta (below 4 Hz) associated with non-REM sleep, Theta (between 4 and 8 Hz) associated with sleep, Alpha (between 8 and 13 Hz) associated with relaxation, Beta (13 to 30 Hz) associated with mental arousal, and Gamma (above 30 Hz) activated during high-level information processing [17]. The most prominent EEG indicator thereof is Alpha band, which has been shown to have good test reliability, high reproducibility, and can detect early stages of annoyance, subjective preference, and restoration [18-20]. Some investigators recorded EEG Alpha rhythm while participants were exposed to different soundscapes [21, 22]. However, previous research did not investigate the effect of indoor acoustics scenarios comprising neighbours sounds on restorative EEG Alpha rhythm.

The present study, therefore, set out to investigate the effects of neighbour sound sources in wooden residential buildings on restorative EEG Alpha wave response. A laboratory experiment was performed, focusing on the effect of impact sounds caused by adult's walking upstairs and airborne sounds coming from neighbouring units including speech and music. It was first hypothesised that α-EEG might be different across the type of sound source and across sound sources heard through partitions characterised by different sound insulation performances. Accordingly, all the sound stimuli were filtered to represent different sound insulation performances of vertical and horizontal partitions in lightweight buildings. Thus, participants listened to a series of acoustic stimuli resembling neighbours sounds through various partitions while wearing an EEG monitoring system B-alert x24®. Additionally, it was hypothesised that reactions to such sounds may be different across residents with different sensitivity to noise or different attitudes towards their neighbours; hence, these two non-acoustic factors were introduced as mediating α-EEG responses.

2. METHODOLOGY

2.1. Participants

Participants were recruited after receiving ethical approval from the Research Committee of the Fire Insurers Laboratories of Korea (FILK) and from the Central Ethics Committee of University of Liverpool. A total of 30 adults with self-reported normal hearing and aged between 20 and 49 years old (mean 40 std 8.6) took part in the experiment. Before the experiment, each participant was asked to answer several questions about their demographic information, noise sensitivity, and attitude towards neighbours. Noise sensitivity was evaluated using a translated version of the 12-items questionnaire NoiSeQ-R [23] with an additional generic item ‘I am sensitive to noise’. According to their overall noise sensitivity score, participants were then divided into low and high noise sensitivity groups. Attitude towards neighbours was assessed using five questions based on the quotes from the interviewees [24] to identify the degree at which participants have a favourable attitude towards neighbours and is reported in Table 1.

Table 1: Five items used to identify the degree of positive attitude towards neighbours of participants.

n.	Item
1	I am close to neighbours
2	I exchange cards or gifts with neighbours
3	I do not want to encounter neighbours
4	I’ve considered moving due to neighbours
5	I sometimes cannot understand neighbours’ behaviours

2.2. Experimental design

The laboratory experiment was conducted at the Fire Insurers Laboratories of Korea (FILK), in a sound-proof room with a low background noise level (~25 dBA). The floor area was about 35.7 m^2 (4.8 m × 7.43 m), which simulates the area of a living room in common apartments. Participants were sitting on a comfy chair while wearing the EEG headset. The stimuli were presented through loudspeakers (GENELEC - 8030A) and a subwoofer (GENELEC – 7060B) which was placed in front of the participants. Sound above 63 Hz was presented via the loudspeakers, while low-frequency sounds below 63 Hz were presented via the subwoofer. White noise (NC 25) was presented through a loudspeaker (GENELEC - 8050A) throughout the experiment as ambient noise in the living room. During the experiment, participants were asked to imagine being relaxing in their own homes while sound stimuli were presented. Following a sequence composed of 20 s baseline and 20 s stimuli presentation, each of the impact and airborne sound sources was presented for a total of 10 minutes. All sound sources were randomised across participants to avoid order effects.

2.3. Sound stimuli

The sound stimuli were impact and airborne sounds which are commonly heard from neighbouring units in wooden residential dwellings. The impact sound source was recorded in a laboratory equipped with different wooden floors: a timber joist slab with a chipboard panel on top, and the same structure equipped with a floating floor and a suspended ceiling. The recordings were made using a binaural head equipped with two half-inch microphones (Type 40HL, GRAS) representing a person sitting on a sofa in the receiving room, while in the source room an adult (1.65 m, 50 kg) walked at a normal speed (1.8 s^{-1}) along the floor sample wearing socks. Sound pressure levels (L_{AFmax}) ranged from 50 to 30 dB for the adult walking across the two floor configurations which were characterised by $L_{n,w}$ = 76 dB and $L_{n,w}$ = 37 dB, respectively. The footsteps 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 (‘speech’), and a piece of classical piano music (‘music’). Both clips were digitally filtered using Adobe Audition to resemble lightweight partitions with different sound insulation performances. The weighted sound reduction indices (R_w) of the two simulated partitions were R_w=52 and R_w=33 dB. For the simulated partition with R_w=52 dB, the sound levels (L_{Aeq}) were 24 dB and 25 dB, respectively for speech and music, for the poor partitions with R_w =33 dB, the levels were 42 dB and 44 dB, respectively for speech and music. Figure 1 illustrates the frequency characteristics and SPL of the selected stimuli.

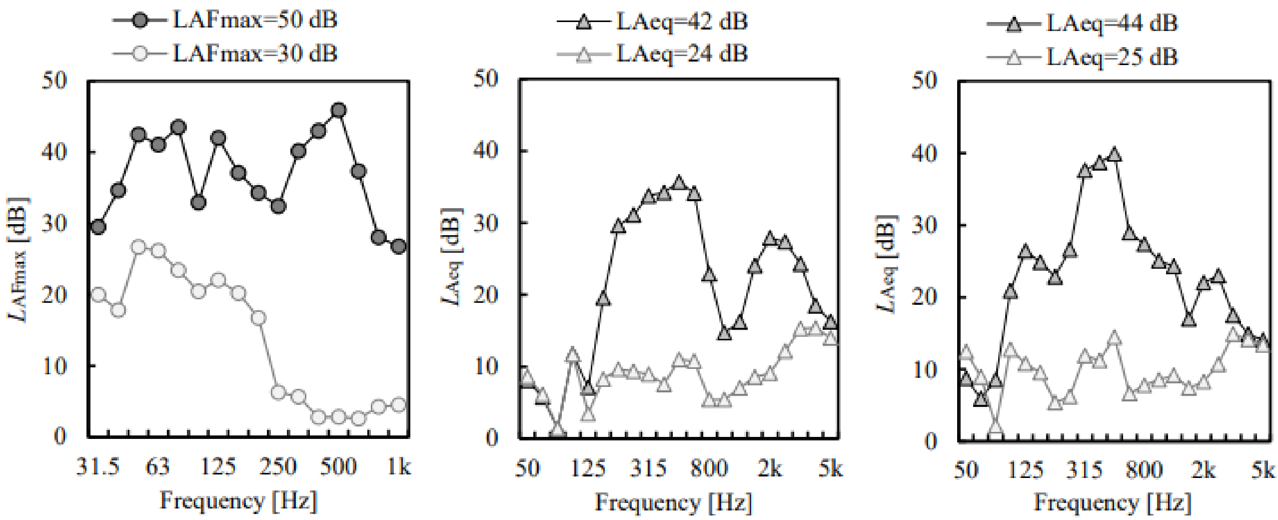

Figure 1: Frequency characteristics and SPL of sound stimuli: footsteps from adult walking (left), speech (middle), and music (right).

2.4. EEG acquisition

The B-Alert® X24 wireless EEG system (Advanced Brain Monitoring, Carlsbad, CA) was used for EEG data acquisition. In accordance with the International 10-20 system, the following 14 EEG channels were acquired: Fp1 and Fp2 (pre-frontal area), F3, F4, Fz, F5 and F6 (frontal area), T3, T4, T5 and T6 (temporal area), C3, Cz and C4 (central area), P3, Pz and P4 (parietal area) and left and right mastoids. Data were collected at a sampling rate of 256 Hz, and the following bandpass characteristics: 0.1 Hz high-pass filter, 100 Hz fifth-order low-pass filter. To avoid artefacts related to eye movements, participants were asked to keep their eyes closed during the stimuli presentation.

Data from B-Alert® X24 were monitored through STAT software (03.08.03.00 version). The recorded EEG data were digitally bandpass filtered using Butterworth filters with cut-off frequencies at 8 and 13 Hz for isolating Alpha waves. Root-mean-squares (RMS) of each epoch were then computed considering the first 10 s of the stimuli presentation.

3. RESULTS AND DISCUSSION

3.1. EEG Alpha waves in response to neighbours sounds

Restorative EEG Alpha activity was acquired during the listening test, imported in the STAT software, and afterwards in Matlab R2017a for the extraction of EEG Alpha running power during each stimulus presentation and at each sensor position. From the running power, the average EEG Alpha activity was then computed. Figure 2 shows the overall α-EEG response for footsteps, speech, and music sounds, along with results for the pre-frontal, frontal, temporal, central and parietal areas. Statistical analysis was conducted to identify the difference between SPLs of each sound source. Independent *t*-tests showed that the overall α-EEG response was significantly different (p<0.05) when listening to footsteps sounds at 30 or 50 dB (L_{AFmax}), with higher activity elicited at the lower SPL. Similarly, for speech, sounds at 24 dB (L_{Aeq}) were eliciting an overall significantly higher α-EEG response (p<0.05) compared to sounds at 42 dB (L_{Aeq}). When hearing music sounds the trend was the opposite, the higher α-EEG response was elicited by the music clip at 44 dB (L_{Aeq}) compared to the music clip at 25 dB (L_{Aeq}), and their difference was significant (p<0.01). Higher α-EEG is typically associated with preferred conditions [25, 26], thus, these findings suggest that the sound insulating performances of both, horizontal and vertical partitions, significantly influence the α-EEG of potential residents.

The effect of the sound source type was investigated using ANOVA. Results varied across presentations with minimum SPLs (footsteps at 30 L_{AFmax}, speech at 24 dB L_{Aeq}, and music at 25 dB L_{Aeq}) or maximum SPL (footsteps at 50 L_{AFmax}, speech at 42 dB L_{Aeq}, and music at 44 dB L_{Aeq}). For instance, the difference in α-EEG response was not significant when listening to sound sources with minimum SPLs [F (2,1797) = 2.193, p=0.112]; however, the difference was significant when sound sources were presented at higher SPLs [F (2,1797) = 20.368, p<0.01]. For the average of the SPLs at which sounds were presented, significant differences in EEG Alpha waves were elicited by footsteps, speech, and music sounds [F (2,3717) = 4.331, p<0.05]. Particularly, Speech and music elicited the lowest and highest α-EEG responses, respectively. A *post-hoc* test confirmed that the difference between speech and music was significant (p<0.01). These findings show that the type of sound source, as well as SPL, has a significant influence on the α-EEG response. In particular, no significant difference was found between impact or airborne sources, whereas significant differences were found between the two airborne types. This may be explained by the specific content of the airborne sound clips used in this experiment, which evoked different emotions. In a previous study using the same sound stimuli [13], it was found that the speech clip elicited higher arousal (i.e., more exciting) and lower valence (i.e., less pleasant) compared to the music clip.

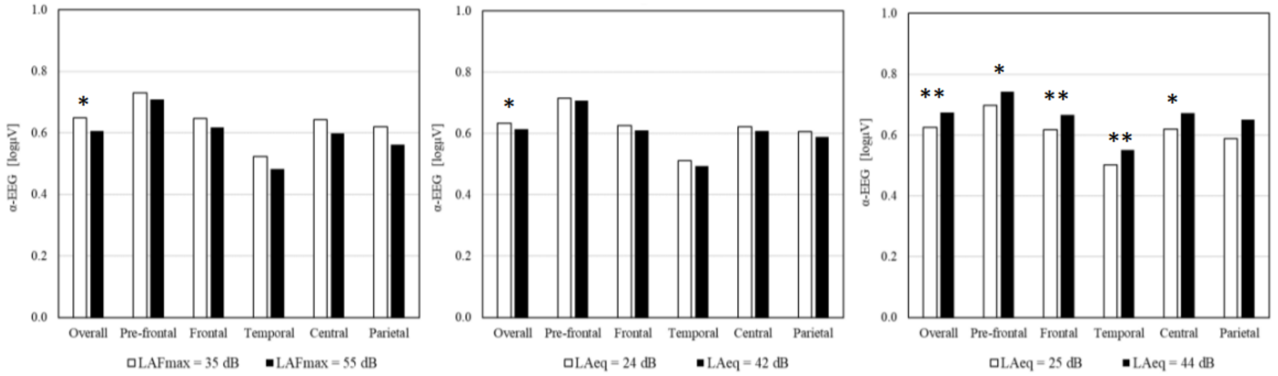

Figure 2: α-EEG responses to impact and airborne sound stimuli: footsteps from adult walking (left), speech (middle), and music (right); * p<0.05, **p<0.01.

3.2. Effect of non-acoustic factors on EEG Alpha waves

Noise sensitivity and attitude towards neighbours were introduced as non-acoustic factors mediating α-EEG response to sounds in the present study. Participants were divided into a low and high noise sensitivity group based on their overall score on the NoiSeQ-R questionnaire [23]. To observe a clear difference between the two 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 13 participants who scored below the 40th percentile were classified as the 'low noise-sensitivity group' (median = 19 and std = 2.2), while the 13 participants who scored above the 60th percentile were classified as the 'high noise-sensitivity group' (median = 28 and std = 3.7). For the two noise sensitivity groups, significant differences (p<0.01) were found in the overall α-EEG response to footsteps, speech, and music sounds. The low noise-sensitivity group showed a larger α-EEG response compared to the high-noise sensitivity group. When a person is in a relaxed status, the EEG-α will rise [22]; thus, this indicates that neighbours sounds are less likely to affect relaxation in residents with lower sensitivity to noise. As reported in Figure 3, the difference between the α-EEG responses of the two noise sensitivity groups was statistically significant (p<0.01) also for various specific areas, including pre-frontal, frontal, temporal, central and parietal for footsteps and speech sounds, and pre-frontal, frontal and central (p<0.05) for the music clip.

To identify participants with a good or poor attitude towards their neighbours, 11 participants who scored below the 40th percentile were grouped into the 'poor attitude towards neighbours group' (median=5 and std=2.3), while the 12 participants who scored above the 60th percentile were classified as the 'good attitude towards neighbours group' (median = 11 and std = 0.9). It was found that attitude towards neighbours had a significant effect (p<0.01) on overall α-EEG response to all the sound stimuli, and participants with a good attitude towards neighbours reported higher α-EEG response compared to participants with a poor attitude towards their neighbours. This indicates that neighbours sounds are less likely to affect relaxation in residents with a good attitude towards their neighbours. More details on the effect of attitude towards neighbours on each scalp area are presented in Figure 4. Significant differences (p<0.01) in specific frontal and temporal and areas were identified for the two airborne sound sources; particularly, speech sound generated significant different α-EEG responses (p<0.05) among the two groups also in the parietal area. Taken together, these findings suggest that non-acoustic factors, including noise sensitivity and attitude towards neighbours, have a significant effect on α-EEG response to neighbours sounds.

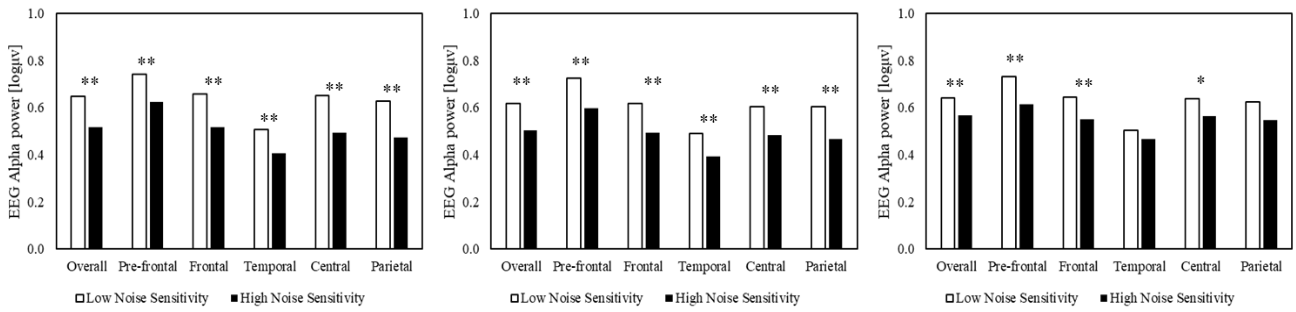

Figure 3: Effect of noise sensitivity on α-EEG: footsteps (left), speech (middle), and music (right); * $p<0.05$, ** $p<0.01$.

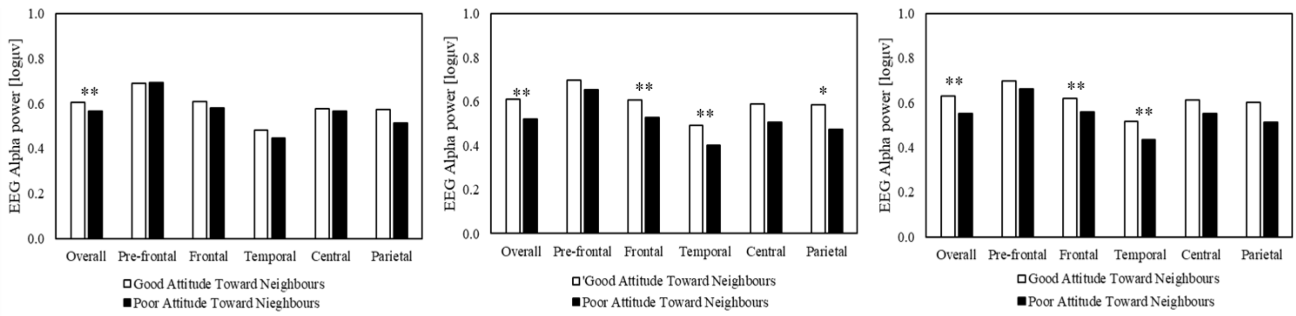

Figure 4: Effect of attitude towards neighbours on α-EEG: footsteps (left), speech (middle), and music (right); * $p<0.05$, ** $p<0.01$.

4. CONCLUSIONS

This study aimed at exploring the effect of commonly heard neighbours sounds on restorative EEG Alpha wave response. It was found that partitions through which sound sources are heard generate a significant difference in α-EEG response. Particularly, footsteps impacting horizontal partitions characterised by good sound insulation performance ($L_{n,w}$ =37 dB) generated a significantly higher restorative α-EEG response compared to sounds from footsteps on a basic timber floor structure ($L_{n,w}$ = 76 dB). The acoustic performances of vertical partitions were also found to significantly influence the α-EEG response. For instance, speech sounds heard through a partition wall performing acoustically good (R_w=52 dB) elicited significantly higher overall α-EEG compared to the same sounds heard through a partition performing acoustically poorly (R_w=33 dB). For the classical music clip instead, the opposite trend was identified. The type of sound source also significantly affected the α-EEG response; particularly a significant difference was found between the two airborne sources (i.e., speech and music). Eventually, noise sensitivity and attitude towards neighbours were found to significantly mediate the α-EEG response. Participants with low noise-sensitivity and good attitude towards neighbours experienced higher α-EEG response to sounds from neighbours, indicating that their relaxation is less likely to be affected by neighbours sounds compared to participants with high noise-sensitivity and poor attitude toward neighbours.

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