Audio-visual interactions in environmental noise perception and the link to urban greening

Timothy Van Renterghem

Ghent University, Department of Information Technology, WAVES research group, Technologiepark 126, B 9052 Gent-Zwijnaarde, Belgium

Abstract - Although physical noise abatement (decibel reduction) is possible with well-designed green infrastructure, the effects of urban greenery on sound perception are often stronger and easier to obtain. This can be attributed to audio-visual interactions, which play a crucial role in environmental noise perception. There is substantial evidence that compelling visual elements, such as greenery, can mitigate the negative effects of environmental noise exposure. Green window view, or seeing outdoor vegetation through the windows of one's dwelling, has been extensively studied before with relation to self-reported road traffic noise annoyance. Studies include long-term noise annoyance assessed at the dwelling through surveys, but also virtual reality experiments in the lab. To incorporate this concept into urban sound planning, design guidelines are needed to optimize the benefits of positive audio-visual interactions. Two recent virtual reality experiments will be discussed, aiming to determine the optimal quantity and quality of greenery. Further research gaps are identified, including the need for more grounded equivalent level reductions to quantify the effect easily, the expected non-linearity of this effect, and the influence of personal factors.

1 INTRODUCTION

People often evaluate vegetation between a sound source and a listener as an effective noise abatement measure, although measured sound pressure level reductions frequently do not support this claim. Studies have shown that even dense and thick hedges (Van Renterghem et al., 2014) or a single row of trees (Jang et al., 2015) are not at all effective in reducing road traffic noise. Notwithstanding, many respondents to surveys viewed vegetation "as a viable alternative to noise barriers", with some claiming their experience confirmed this (Perfater, 1979). Yang et al. (2011) found that 90% of people thought landscape plants helped reduce noise, and 55% overestimated the plants' actual noise-attenuating ability. Another example is a survey by Aletta et al. (2018) along a bike path next to a major highway with visible vegetation and measured sound pressure levels over 70 dBA. Surprisingly, 45% of respondents described the environment as "calm" rather than "busy." Additionally, there are many instances where removing a row of trees along a road or pruning activities led to increased noise complaints from nearby residents, despite no significant increase in (measured) sound pressure levels.

One plausible explanation for these findings is that the general public does not differentiate between the actual physical reduction of noise and effects related to perception. When people evaluate loudness or self-reported noise annoyance, they implicitly include perception effects, which they often attribute to an apparent physical reduction in sound pressure levels. These aforementioned studies and assertions highlight the significant and positive impact of vegetation on the perception of environmental noise.

Audio-visual interactions in environmental perception are essential to understand the aforementioned phenomenon. Human environmental perception is essentially multi-sensorial. People use all their senses to acquire as much information as possible to make a mental image of their surroundings (e.g. to anticipate danger), an essential process for our evolutionary survival. If there are multiple relevant inputs, at some point, these have to be merged in our brains and will interact.

The pivotal work of Macdonald and Lavie (2011) pointed at the concept of inattentional deafness. In their experiment, a test panel was asked to visually evaluate a cross presented on a computer screen. In a low cognitive load condition, it was asked whether the horizontal or vertical arm of that cross was blue or green. In a high load condition, it was asked which arm of the cross was slightly longer. At the same time, white noise was played through headphones. Occasionally, a pure tone was added to this noise sequence. After completion of the visual tasks, participants were asked what they have heard. While in the low-load condition most people mentioned the tonal components added to the noise sequence, this dropped strongly in the high load condition. Also when presenting the tonal noise alone, so without being submersed in white noise, similar results were obtained during the high load visual case. The authors concluded that a visual task is able to suppress the noticing of task-irrelevant auditory cues. This also points at the fact that there is a shared attentional capacity between modalities (here vision and hearing) in our brains. When extending this idea to environmental noise perception, a visual that attracts attention could divert the attention away from environmental noise, which is usually an irrelevant stimulus.

The link with green infrastructure can be easily made. Vegetation is known to easily attract and sustain human attention, and could contribute to the previously discussed inattentional deafness. There are two famous frameworks that further justify why vegetation is relevant in this context. Kaplan and Kaplan (1989) developed the attention restoration theory (ART). Basically, there are two types of attention. First, there is directed attention, which needs effort and becomes depleted or leads to fatigue. Secondly, there is effortless attention or soft fascination. Directed attentional resources are restored during periods of effortless attention. Vegetation has the ability to provide the necessary soft fascination. Secondly, there is the stress reduction theory (SRT) by Ullrich (1983). Seeing vegetation reduces stress because we know we have access to features like water, food and shelter, essential for (primitive) human functioning, but still deep coded in our brains nowadays. Especially after a period of stress, this has a soothing function. Note that preference, relaxation and assigning aesthetic value to greenery are constructs that are all intertwined (Van den Berg et al., 2003).

In this paper, we will focus on the impact of seeing vegetation through the windows of one’s dwelling and noise annoyance in response to road traffic noise. Following the aforementioned hypotheses and explanations, positive effects can be expected. Furthermore, this idea is directly applicable to the many urban situations where common road traffic noise abatement measures are hard to apply or are ineffective.

2 GREEN WINDOW VIEW AND ROAD TRAFFIC NOISE ANNOYANCE

2.1 Current real life evidence

There is substantial real-world evidence suggesting that seeing outdoor vegetation through home windows can alleviate noise annoyance. For example, Li et al. (2010) found that visible greenery reduced self-reported noise annoyance among high-rise building residents, with extensive greenery and parks leading to a 2-point decrease in annoyance on an eleven-point scale compared to no greenery. In Ghent, Belgium, residents living along a noisy inner-city ring road who had views of outdoor vegetation from their living rooms reported significantly lower levels of noise annoyance. Without vegetation views, there was a 34% likelihood of being at least moderately annoyed by road traffic noise (scoring 3 or higher on a 1-to-5 scale), which decreased to 8% with substantial vegetation views (Van Renterghem and Botteldooren, 2016). Additionally, Leung et al. (2017) reported that the probability of high annoyance was 26% when viewing walls, but only 5% with greenery views. A Swiss national noise annoyance survey (Schäffer et al., 2020) incorporating spatial green analysis at each address found that neighbourhood greenery corresponded to a 6 dB equivalent noise reduction in road traffic noise annoyance. Schäffer et al. (2020) also noted that in urban areas, actual views of outdoor greenery were more impactful than in rural settings.

2.2 Mechanisms

First of all, the concept of inattentional deafness can be mentioned : a compelling visual such as vegetation view might suppress the attention given to the environmental noise and consequently less annoyance experienced. Secondly, noise exposure induces stress in the human body. The additional stress caused by exposure to environmental noise (see e.g. Westman and Walter, 1981) could be mitigated by the stress reducing potential of visible natural elements. Thirdly, environmental noise and its processing occupies part of the working memory in the human brain. It is well known, e.g., that in a noisy environment, it becomes more difficult to concentrate on a specific task (see e.g. Stansfeld et al., 1993). Attention restoration provided by vegetation views may be helpful for "*clearing the head*" and "*preventing residual bits and pieces of cognitive leftovers running around and starting the new task with something of a deficit*" (Kaplan and Kaplan, 1989). Indirectly, the stress reduction and attention restoration are likely to be translated by people as experiencing less self-reported noise annoyance.

A further analysis of the key real life evidence from Section 2.1 can shed some more light on the mechanisms involved. In literature, sound source visibility is sometimes discussed as a potential reason why vegetation could help in reducing noise annoyance. In this respect, two competing mechanisms can be identified, namely audio-visual (in)congruency and attention focussing. A deeper discussion on this topic can be found in Van Renterghem et al. (2019). The inner ring road study of Van Renterghem and Botteldooren (2016), although having a smaller number of respondents than the other surveys discussed in Section 2.1, selected address points with very similar most exposed façade levels. In addition, building setups and road configurations were quite similar throughout this dataset, and (measured) living room window acoustic insulation was ruled out as a confounder. Of relevance in the context of source (in)visibility, all respondents saw at least two traffic lanes, so source hiding potential by green infrastructure is clearly not a general decisive mechanism to explain road traffic noise annoyance mitigation by green window view.

Natural sounds cannot explain the observed effects either. Natural sounds, by themselves, haven been shown to have (strong) restorative properties. Natural sounds, augmenting road traffic noise dominated urban parks, were shown before to improve the overall sonic environment (Van Renterghem et al, 2020; Hong et al., 2021). Vegetation is directly linked to the production of natural sounds, both from a geophonic and biophonic (habitat) perspective. The exposure levels at the survey points in the Ghent study (Van Renterghem and Botteldooren, 2016) are all in the range 70-75 dB L_{den}, making it highly unlikely that natural sounds, if present, could attain sufficiently audible sound pressure levels (McClure et al., 2013). In addition, when considering e.g. bird songs, most likely they would have been scared away in this particular area due to the high anthropogenic sound pressure levels.

Combining findings from the Ghent (Van Renterghem and Botteldooren, 2016) and Swiss study (Schäffer et al., 2020) highlights the importance of sufficient salient green spaces. The Swiss study differentiates between urban and rural survey points, revealing that the positive effect of green views is significantly more pronounced in urban areas, where green infrastructure is more noticeable. In contrast, rural environments, where green spaces are abundant, window view greenery may be less spectacular. In the Ghent study, the region of interest generally lacks greenery, making park borders and central reservation vegetation more likely to attract visual attention.

At home, people do not stare all the time through windows. But interestingly, already long time ago, both Kaplan (2001) and Ulrich et al. (1991) came up with the concept of "*micro-restoration*". Many short periods of vegetation view are yet sufficient to lead to attention restoration. In another study, Ulrich found that only a few minutes of nature view could already destress people. Kaplan also discussed how a window's framing effect can be beneficial—it offers a form of miniaturization of the outside world, potentially enhancing the sense of extent, one of the key dimensions of scenic beauty in Attention Restoration Theory (ART).

3 OPTIMIZING GREEN QUALITY AND QUANTITY FOR ROAD TRAFFIC NOISE ANNOYANCE REDUCTION

While the aforementioned studies demonstrate the impact of vegetation views on reducing noise annoyance, they do not directly translate into urban greening design guidelines. Developing such guidelines is crucial for applying this beneficial audio-visual interaction to urban sound planning. The studies discussed in Section 2.1 could indicate that more greenery generally leads to a stronger effect on noise annoyance reduction. In addition, these studies assessed existing conditions, including a mixture of types of green infrastructure (trees, grasslands, wetlands, park borders, etc.).

Ongoing work has been focusing on both the optimal quantity and quality of greenery by means of virtual reality (VR) experiments (see Van Renterghem et al., 2023), allowing full control over the audio-visual environment, and similar to the real life surveys, focussing on self-reported noise annoyance. VR is increasingly recognized as an effective method for studying audio-visual interactions in environmental perception and soundscapes (Li and Lau, 2020), including human-nature interactions (Annerstedt et al., 2013).

In the VR experiments of Van Renterghem et al. (2023), participants were placed near the window of a virtual living room overlooking a city ring road, where the central reservation hosted different greening scenarios. The first experiment focused on varying the quantity of trees to examine the effect of increasing tree density. The second experiment built on the optimal quantity identified in the first experiment, and explored the impact of different green qualities. Figure 1 shows some rendered images of the environment to which the participants were exposed.

The audio stimulus was road traffic noise recorded with a head-and-torso simulator (HATS) positioned in front of a half-opened window (67 dBA at eardrum) in a similar setting as in the VR environment. For a more detailed description of the methodology and setup, the interested reader is referred to Van Renterghem et al. (2023).

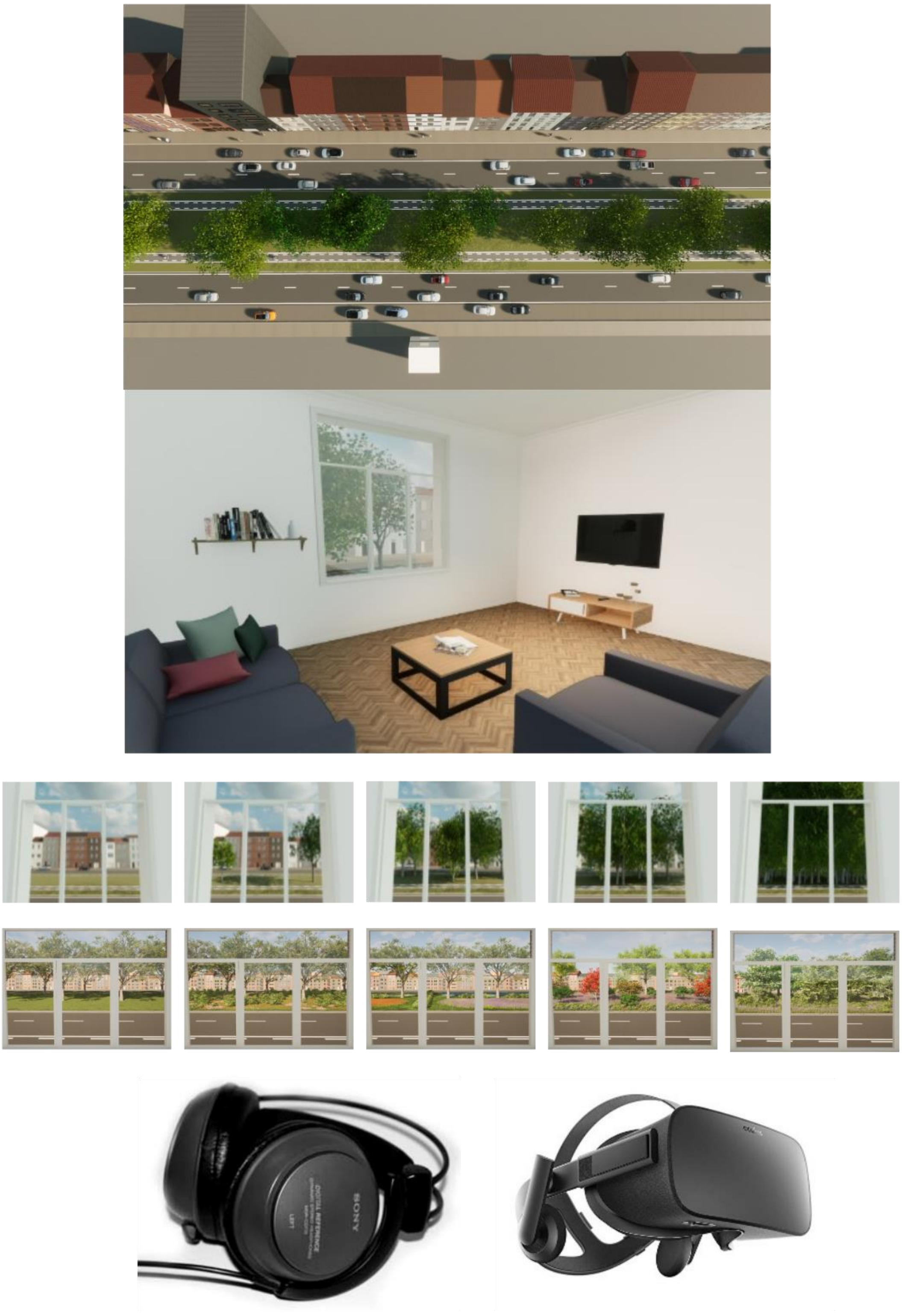

Figure 1 – Rendered virtual reality environment showing the exterior road traffic and the living room at the first floor (of the isolated white building) where the participants were positioned, in front of the window. Five window views were assessed with relation to green density of the central reservation tree belt (ranging from 10% to 50% greenish pixels), and five window scenes with relation to green quality. Participants were exposed to the audio-visual environment by means of headphones and VR glasses.

3.1 Towards optimized green quantity

The effect of green quantity on the self-reported noise annoyance is visualized in Fig. 2. With the use of an artificial neural network (ANN) model, based on the actual data (in total 395 datapoints), a number of potentially relevant features (more precisely: audio-visual acuity, growing up in a green or urban environment, living in a green or urban environment, noise sensitivity, audio-visual sensitivity, connectedness-to-nature and perceived stress prior to the experiment) were set to their average value over the test panel, while the green quantity varied. Building the ANN with additional personal features allowed putting green quantity in context. Note that exposure level, generally a major predictor of noise annoyance, was fixed in this experiment.

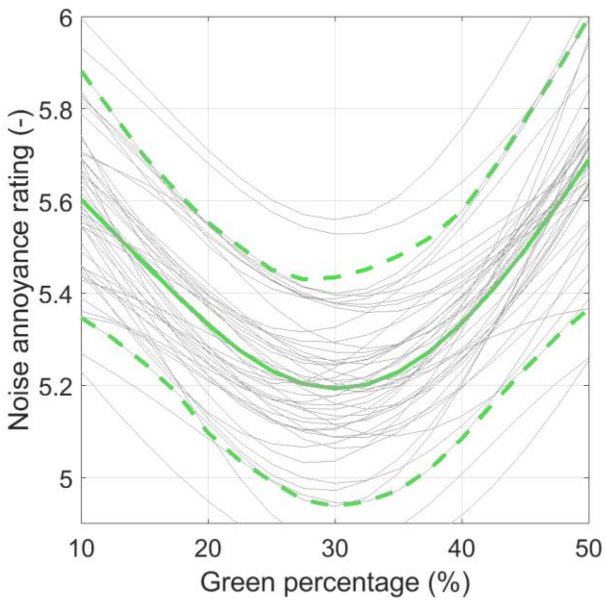

Figure 2 – Modelled (absolute) noise annoyance rating in function of green percentage (full green line) based on the green quantity study. The green dashed lines indicate 90% confidence intervals on repeated model developments by bootstrapping.

A minimum in self-reported noise annoyance is found slightly above 30 %, but the latter is not very pronounced. Over the full range of green percentages considered, a difference of about 0.5 units on the 11-point annoyance Likert scale is observed. The root-mean-square error between measurements and predictions is near 1 unit on the 11-point annoyance scale.

3.2 Towards optimized green quality

In a follow-up VR experiment, using a different test panel, a green percentage near 30 % was used as a starting point. Quality of the green infrastructure was defined along the dimensions species richness, colour richness and maintenance degree. In addition to the main noise annoyance question the overall aesthetic value was assessed at each scenario.

Fig. 3 shows a similar evaluation as for the green quantity, but now with aesthetic value as independent parameter. The aesthetic value ranges from 1 to 5 (with 5 being most beautiful) and lead to a variation of about 1.5 units on the 11-point annoyance scale, showing this is a main driver for the self-reported annoyance in the context of green window view. Aesthetic value can be seen as a direct consequence of the aforementioned quality dimensions. In total, 310 noise annoyance evaluations were considered to build the ANN.

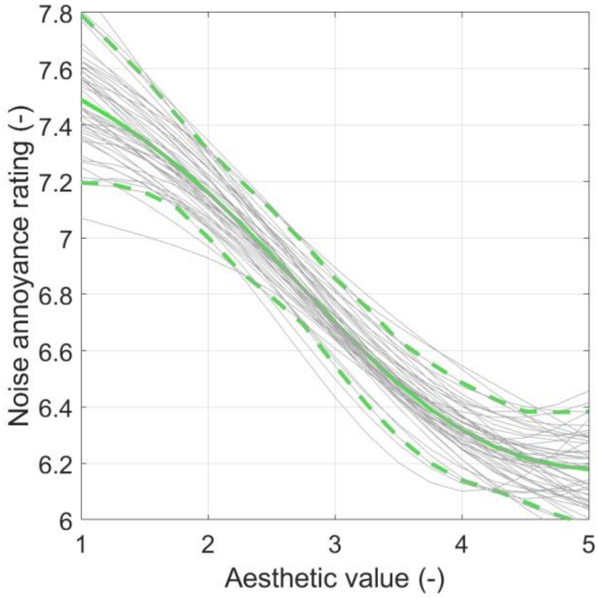

Figure 3 – Modeled (absolute) noise annoyance rating vs aesthetic value (full green line) based on the green quality study. The green dashed lines indicate 90% confidence intervals on repeated model developments by bootstrapping.

4 DISCUSSION

Audio-visual interactions in environmental perception can be strong, and its deliberate application could complement common road traffic noise abatement measures focussing on decibel reduction. Note that purely looking at sound pressure level reductions typically leads to only 30% explained variance with relation to human perception. Green window view for noise annoyance mitigation has become a well-studied case over the last decade, and plausible explaining mechanisms have been formulated. In addition, urban greening brings a myriad of positive effects for dwellers, and environmental noise annoyance mitigation should be added to this list. Notably, the green quality study suggests a link between environmental noise perception improvement and biodiversity, an issue of global importance.

4.1 Equivalent sound pressure level reduction for noise annoyance

Estimating the equivalent noise level reduction could help to position perception-based measures relative to more traditional noise abatement strategies. To achieve this, it is essential to consider a specific effect of noise exposure, such as noise annoyance. Although such an estimate is inherently rough, particularly when based on research not specifically designed to derive such correction factors, key real-life surveys cited in this work suggest a potential noise annoyance reduction between 6-10 dBA. This value aligns well with findings from earlier studies. For instance, Lercher (1996) noted that the aesthetic and natural composition of a site could be as significant as 5 dBA, while Langdon (1976) indicated that the visual appearance of a neighbourhood could theoretically contribute up to 15 dBA in mitigating road traffic noise nuisance.

4.2 Non-linearity

It can be reasonably expected that noise annoyance mitigation by green window view behaves non-linearly. Based on the current evidence, this measure seems applicable to situations where noise levels are as high such as 70-75 dBA simulated L_{den} (Van Renterghem and Botteldooren, 2016), and CRTN predicted levels around 64 dBA ($L_{A,10}$) in Leung et al. (2017). In the Swiss national study (Schäffer et al., 2020), there was a wide range of exposure levels. The study by Gidlöf-Gunnarsson and Öhrström (2010), although focusing on greenery in quiet courtyards, further support the fact that at higher levels, positive effects are more pronounced. Although not directly comparable, the experiment by Aylor and Marks (1976), looking at semi-transparent barriers, found that the influence of the visual setting was strongest near roughly 75 dB. At the extremes in their test (40 dB and 90 dB), the visuals did not affect loudness judgement anymore. Logically, when exposure levels are too high, the sound intensity becomes too overwhelming to benefit from this positive audio-visual interaction. At very low levels, on the other hand, noise annoyance is hardly an issue and perception improvement can neither be expected. The boundaries, however, are not yet set and more work is needed to substantiate them.

4.3 Sound source type

Although most research regarding the effect of vegetation on noise perception focuses on road traffic, by far the most prominent source of noise annoyance in the built-up environment, its application to other noise sources is still under debate. Although the VR experiment discussed in Lutgen et al. (2018) found positive effects for air traffic as well, the Swiss study reported by Schaeffer et al. (2020) saw increased annoyance in case of air traffic noise combined with visible greenery.

4.4 Personal factors

For the majority of participants to surveys discussed, green window view leads to road traffic noise annoyance mitigation. However, the way personal factors interact here is still an open question. Constructs such as nature connectedness (Mayer and McPherson-Frantz, 2004) or nature relatedness (Zelenski and Nisbet, 2014) could play here, potentially influenced by early childhood nature experiences (Rosa et al, 2018).

In addition, some people might be more visually or auditory dominated (Giard and Peronnet, 1999), and the concept of audio-visual aptitude has been put forward (Sun et al., 2018). In the latter study, a proportion of the respondents were more easily distracted by visual information in audio-visual exposures. Age might also be relevant. Hasher and Zacks (1988) reported an age-related decline in divided attention and normal inhibitory processes, suggesting that older adults may be less able than younger ones to suppress a visual distractor. Consequently, the concept might work better for an older population.

4.5 Physical sound pressure level reduction with vegetation

The current focus on audio-visual interactions with relation to greenery does not mean that physical noise reduction with vegetation should be disregarded. Similarly to any noise abatement measure, the green infrastructure should be well designed. Note that vegetation modules in standardized outdoor sound propagation models like ISO9613-2 (1996) or similar are most often very conservative when it comes to predicted attenuations attributed to sound propagation through vegetated areas. The regression curves used in the ISO9613-2 model were developed on empirical research only, where a situation "*as is*" is measured, and the primary focus was on scattering by leaves. For road traffic noise, wavelengths of relevance are much too large relative to common leaf sizes, making this process rather ineffective.

Tree belts along road, e.g., have been well studied. When a mature forest floor ground effect and closely spaced tree trunks are combined, relevant road traffic noise abatement is possible, even when the belt width is limited (Van Renterghem, 2014). Based on full-wave numerical simulations, some interesting approaches have been identified to relax the need for high biomass density, without affecting noise shielding to an important extent. Guidelines for mitigating road traffic noise with tree belts recommend using rectangular planting schemes, introducing pseudo-randomness within the tree belt, and occasionally omitting rows of trees parallel to the road (Van Renterghem, 2014). Although tree bark absorption is limited, some species have more absorbing barks (Li et al., 2020). Especially in denser belts, characterized by many interactions due to the multiple scattering process, a small increase in bark absorption could be relevant for physical noise abatement.

5 CONCLUSIONS

There is substantial evidence that green window view, or seeing outdoor vegetation through the windows of one's dwelling, is effective in mitigating self-reported road traffic noise annoyance at home. Plausible underlying mechanisms were put forward. Continued research in well-controlled virtual reality environments showed there is an optimum green density, and more importantly, green quality and visual aesthetics of the vegetation are the main drivers of this audio-visual interaction effect.

ACKNOWLEDGEMENTS

I would like to thank the organisers of Acoustics Australia 2024 for inviting me as a plenary speaker and to write this companion paper. The core of this work is based on a number of surveys and VR experiments performed at Ghent University, and my gratitude goes to students Elin Vermandere, Maarten Lauwereys and Jochen Ahmad at the Faculty of Engineering and Architecture for their significant contributions, and Dick Botteldooren for fruitful discussions in the context of this topic.

REFERENCES

Annerstedt, M., Jönsson, P., Wallergård, M., Johansson, G., Karlsson, B., Grahn, P., Hansen, Å.M., & Währborg, P. (2013). Inducing physiological stress recovery with sounds of nature in a virtual reality forest: results from a pilot study. Physiology & Behavior, 118, 240-250.

Aletta, F., Van Renterghem, T., Botteldooren, D. (2018). Influence of personal factors on sound perception and overall experience in urban green areas. A case study of a cycling path highly exposed to road traffic noise. International Journal of Environmental Research and Public Health, 15, 1118.

Aylor, D., & Marks, L. (1976). Perception of noise transmitted through barriers. Journal of the Acoustical Society of America, 59, 397–400.

Giard, M., & Peronnet, F. (1999). Auditory-Visual Integration during Multimodal Object Recognition in Humans: A Behavioral and Electrophysiological Study. Journal of Cognitive Neuroscience, 11, 473–490.

Gidlöf-Gunnarsson, A., & Öhrström, E. (2010). Attractive "quiet" courtyards: A potential modifier of urban residents' responses to road traffic noise? International Journal of Environmental Research and Public Health, 7, 3359–3375.

Hasher, L., & Zacks, R. (1988). Working memory, comprehension, and aging: A review and a new view. In: Psychology of Learning and Motivation, Elsevier, Amsterdam, The Netherlands.

Hong, J. Y., Lam, B., Ong, Z.-T., Ooi, K., Gan, W.-S., Kang, J., Yeong, S., Lee, I., Tan, S.-T., 2021. A mixed-reality approach to soundscape assessment of outdoor urban environments augmented with natural sounds. Building and Environment 194, 107688.

ISO 9613-2 Acoustics – attenuation of sound during propagation outdoors – Part 2. International Organisation for Standardisation, Geneva, Switzerland, 1996.

Jang, H., Lee, S. Jeon, J., & Kang, J. (2015). Evaluation of road traffic noise abatement by vegetation treatment in a 1:10 urban scale model. Journal of the Acoustical Society of America, 138, 3884-3895.

Kaplan, R., & Kaplan, S. (1989). The experience of nature: A psychological perspective. Cambridge University Press, New York, US.

Kaplan, R. (2001). The Nature of the View from Home: Psychological Benefits. Environment and Behaviour, 33, 507-542.

Langdon, F. (1976). Noise nuisance caused by road traffic in residential areas: part 1. Journal of Sound and Vibration, 47, 243-263.

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

Leung, T., Xu, J., Chau, C., Tang, S., & Pun-Cheng, L. (2017). The effects of neighborhood views containing multiple environmental features on road traffic noise perception at dwellings. Journal of the Acoustical Society of America, 141, 2399-2407.

Li, H., Chau, C., & Tang, S. (2010). Can surrounding greenery reduce noise annoyance at home? Science of the Total Environment, 408, 4376–4384.

Li, H., & Lau, S.-K. (2020). A review of audio-visual interaction on soundscape assessment in urban built environments. Applied Acoustics, 166, 107372.

Li, M., Van Renterghem, T., Kang, J., Verheyen, K., & Botteldooren, D. (2020). Sound absorption by tree bark. Applied Acoustics, 165, 107328.

Lugten, M., Karacaoglu, M., White, K., Kang, J., & Steemers, K. (2018). Improving the soundscape quality of urban areas exposed to aircraft noise by adding moving water and vegetation. Journal of the Acoustical Society of America, 144, 2906.

Macdonald, J., & Lavie, N. (2011). Visual perceptual load induces inattentional deafness. Attention, Perception, & Psychophysics, 73, 1780–1789.

Mayer, F., & McPherson-Frantz, C. (2004). The connectedness to nature scale : A measure of individuals' feeling in community with nature. Journal of Environmental Psychology, 24, 503-515.

McClure, C., Ware, H., Carlisle, J., Kaltenecker, G., & Barber, J. (2013). An experimental investigation into the effects of traffic noise on distributions of birds: avoiding the phantom road. Proceeding of the Royal Society B 280:20132290.

Perfater, M. (1979). Community perception of noise barriers, volume 1. Report of Virginia Highway and Transportation research council, US (VHTRC 80-R14).

Rosa, C., Profice, C., & Collado, S. (2018). Nature Experiences and Adults' Self-Reported Pro-environmental Behaviors: The Role of Connectedness to Nature and Childhood Nature Experiences. Frontiers in Psychology, 9, 1055.

Schäffer, B., Brink, M., Schlatter, F., Vienneau, D., & Wunderli, J.-M. (2020). Residential green is associated with reduced annoyance to road traffic and railway noise but increased annoyance to aircraft noise exposure. Environment International, 143, 105885.

Stansfeld, S., Sharp, D., Gallacher, J., & Babisch, W. (1993). Road traffic noise, noise sensitivity and psychological disorder. Psychological Medicine, 23, 977-985.

Sun, K., Echevarria-Sanchez, G., De Coensel, B., Van Renterghem, T., Talsma, D., & Botteldooren, D. (2018). Personal audiovisual aptitude influences the interaction between landscape and soundscape appraisal. Frontiers in Psychology: Environmental Psychology, 9, 780.

Van den Berg, A. E., Koole, S.L., & van der Wulp, N.Y. (2003). Environmental preference and restoration: (How) are they related? Journal of Environmental Psychology, 23, 135-146.

Van Renterghem, T. (2014). Guidelines for optimizing road traffic noise shielding by non-deep tree belts. Ecological Engineering, 69, 276–286.

Van Renterghem, T., Attenborough, K., Maennel, M., Defrance, J., Horoshenkov, K., Kang, J., Bashir, I., Taherzadeh, S., Altreuther, B., Khan, A., Smyrnova, Y., & Yang, H. (2014). Measured light vehicle noise reduction by hedges. Applied Acoustics, 78, 19-27.

Van Renterghem, T., & Botteldooren, D. (2016). View on outdoor vegetation reduces noise annoyance for dwellers near busy roads. Landscape and Urban Planning, 148, 203-215.

Van Renterghem, T. (2019). Towards explaining the positive effect of vegetation on the perception of environmental noise. Urban Forestry and Urban Greening, 40, 133-144.

Van Renterghem, T., Vanhecke, K., Filipan, K., Sun, K., De Pessemier, T., De Coensel, B., Joseph, W., & Botteldooren D. (2020). Interactive soundscape augmentation by natural sounds in a noise polluted urban park. Landscape and urban planning, 194, 103705.

Van Renterghem, T., Vermandere, E., & Lauwereys, M. (2023). Road traffic noise annoyance mitigation by green window view: optimizing green quantity and quality. Urban Forestry and Urban Greening, 88, 128072.

Ulrich, R. (1983). Aesthetic and affective response to natural environment. In : Altman and Wohlwill (Eds.), Behavior and the natural environment: Vol. 6. Human behavior and environment. Plenum Press, New York, US.

Ulrich, R., Simons, R., Losito, B., Fiorito, E., Miles, M., & Zelson, M. (1991). Stress recovery during exposure to natural and urban environments. Journal of Environmental Psychology, 11, 201-230.

Westman, J., & Walter, J. (1981). Noise and Stress: A Comprehensive Approach. Environmental health perspectives, 41, 291-309.

Yang, F., Bao, Z., & Zhu, Z. (2011). An assessment of psychological noise reduction by landscape plants. International Journal of Environmental Research and Public Health, 8, 1032–1048.

Zelenski, J., & Nisbet, E. (2014). Happiness and Feeling Connected: The Distinct Role of Nature Relatedness. Environment and Behavior, 46, 3-23.