Effect of interaction between attention focusing capability and visual factors on road traffic noise annoyance

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Abstract: In recent decades, noise annoyance has been investigated thoroughly as one of the most prominent effects of traffic noise. Still, the influence of visual factors on sound perception is not completely understood. Audiovisual attention focusing and gating are expected to play a role at the perceptual stage. This would also imply the existence of inter-person differences in exposure-effect relationships beyond known factors such as noise sensitivity. To explore these hypotheses, an experiment was designed that combines a newly designed test on audiovisual attention focusing capabilities with a noise annoyance experiment conducted in a mockup living room. The noise annoyance experiment used 16 audiovisual stimuli, which are a combination of 4 window-view video sceneries and 4 sound fragments, to investigate the relative importance of sound source visibility and green elements visibility. In this setting, it was found that (1) sound source visibility, as a functional parameter of the visual setting, has more impact on self-reported noise annoyance than the green element's visibility which describes the quality of the visual; (2) self-reported noise sensitivity remains the strongest personal factor, yet persons being easily distracted by visual elements report significantly lower noise annoyance at the same exposure level; (3) two significant interactions were observed in the prediction of self-reported noise annoyance: (a) noise sensitivity interacts with sound source visibility; (b) vision dominance, as a personal factor, interacts with the visibility of green elements. The interaction between these factors provides additional evidence to support the role of audiovisual attention in the emergence of noise annoyance.

Keywords: attention, noise sensitivity, audio-visual interactions, noise annoyance, road traffic noise

1. Introduction

In recent decades, the relationship between noise exposure and annoyance, especially in and around the dwelling, has been explored in depth [1][2]. Hence, noise annoyance has now been recognized by the World Health Organization as the strongest and best proven effect of environmental noise on people. For the European Union's noise indicator, L_{den}, exposure effect relationships have been derived [3]. It has also been shown that noise annoyance could be an indicator for effects of noise on health and well-being [4][5][6]. The determinants of annoyance were investigated in related studies leading to complex models [7][8]. Epidemiological research has indeed shown that not only the average sound level influences annoyance, but also personal factors modify the exposure effect relationship (such as age, gender, education and noise sensitivity, as well as other environmental factors [9][10][11]). In particular, subjective noise sensitivity was shown to be a very stable personality trait which is determined both by inheritance and experience [12][13][14][15][16].

In environmental noise surveys, the effect of visual elements such as the view from the window on long-term noise annoyance have been addressed before [17][18][19][20], yet less frequently than other contextual factors. Audiovisual interactions in combination with noise annoyance in and around the dwelling is a multifaceted effect that is not easy to grasp. In experimental work related to urban environments, the congruence between visual and sound information was strongly affecting the appraisal of the sonic environment, in terms of visual influence [20]. Although congruence may also play a role in occurrence of annoyance in and around the dwelling [22], more basic aspects of the audiovisual experience have been suggested, such as visibility of the sound source [22]. Some studies pointed out that seeing the sound source would increase subjective annoyance [24], others found that visually screened traffic was perceived as more noisy [25][26]. In addition, the general quality of the visual setting and more particularly, the visibility of green elements was shown to have a direct influence. Visually attractive and green noise barriers tend to be more efficient in reducing noise annoyance [27]. Recent research [28] has nevertheless confirmed the complexity of the audiovisual interaction: in a lab experiment, adding visual information to a listening experiment tended to reduce annoyance if the sound source was believed to have a positive influence, while annoyance increased for mechanical sound sources.

Psychophysical knowledge may help understanding the complex influence of visual information on perceived noise annoyance in and around the dwelling. Prior research has shown that noticing sounds can be regarded as a precursor for noise annoyance [29]. In this view, sounds that attract more attention would more likely cause annoyance. Audiovisual stimuli, which are irrelevant for the tasks a person is involved in, may capture involuntary attention, a process where sensory modalities interact at different levels in the brain [30]. This could lead to an increase in annoyance for visible sources. In addition, individual differences in the capability of focusing attention has recently been shown to affect the cocktail party effect [31]. Distractibility may be a personality trait that can be defined also in the healthy population [32]. Hence, it seems useful to study whether distractibility could be a personal factor affecting the influence of the visual scene on noise annoyance or even the emergence of noise annoyance itself.

It should be noted, however, that occasional attention saccades to environmental factors not only cause increased noticing and therefore possible annoyance. Attention restoration theory predicts that such attention switches may enhance restoration and therefore would not be appraised as annoying [33][34]. A better understanding of audiovisual interactions in perception of the environment may lead to better urban planning and soundscape design [35].

In this article, an experimental study is described that aims at confirming the hypothesis on the mechanisms underlying the effect of the view from the window on noise annoyance. In addition, the experiment aims at identifying subjective noise sensitivity and distractibility as personal factors influencing this effect. To be able to go beyond questionnaires for assessing personal factors, we opted for a lab study using well controlled stimuli. Assessing noise annoyance in an ecologically valid way in an experimental setup is rather difficult as the main hidden factor under investigation, i.e. non-voluntary attention, is replaced by focused attention in a listening experiment. For this reason, two specific requirements were introduced in the experimental design. Firstly, the exposure time for each stimulus was 10 minutes and participants were instructed to engage in some light activity during the experiment in order not to focus on the sound. Earlier studies [36][37] have shown that this protocol is valid. Secondly, since the target of this study is the effect of the view from the window, direct comparison between different visual stimuli is avoided by showing the visual stimulus in a natural setting, a mockup window, and by presenting the different visual stimuli on different days. The additional distractibility experiment is conducted at the very end not to reveal the focus on visual information.

2. Methodology

2.1 Overview

The first part of this study is a road traffic noise annoyance experiment conducted in conditions that should resemble the everyday living context as closely as possible. Participants were exposed to 16 audiovisual stimuli (Figure 1) during 4 separate experimental days in the same mockup living room. At each experimental day, the view from the window was fixed and the audio fragments varied. The participants were led to believe this experiment was about rating the perceived annoyance of 16 environmental sound conditions in a living room. Each audiovisual stimulus was played for 10 minutes, in order to give participants enough time to engage in some light activity and to adapt to the living room environment. After the presentation of each audiovisual stimulus, they were asked to rate their perceived noise annoyance during the past 10 minutes on an 11-point scale (from ‘Not at all’ (0) to ‘Very much’ (10) annoyed) [38].

Since detecting the effects of visual factors on sound perception was the objective of this study, all other factors were carefully controlled in order to eliminate their impact on sound perception as much as possible. For example, during each experimental day, participants were asked to sit in the same seat in the mockup living room, which gave them the same perspective to all scenes. It was also assured that the room setup, the lighting, and the room ventilation remained unchanged. The acoustic playback level was controlled by measuring the sound level in the center of the room. Participants were also asked to refrain from drinking alcohol or unusual amounts of coffee or taking medical drugs before the experiment. In addition, it was asked not to listen to loud music while waiting to participate in the experiment.

The design of the experiment assumes that the auditory memory of participants was erased in between experimental days. However, there may still be a degree of habituation to the experimental setup. Therefore the order of presentation of the 4 visual settings during 4 days was randomized between participants.

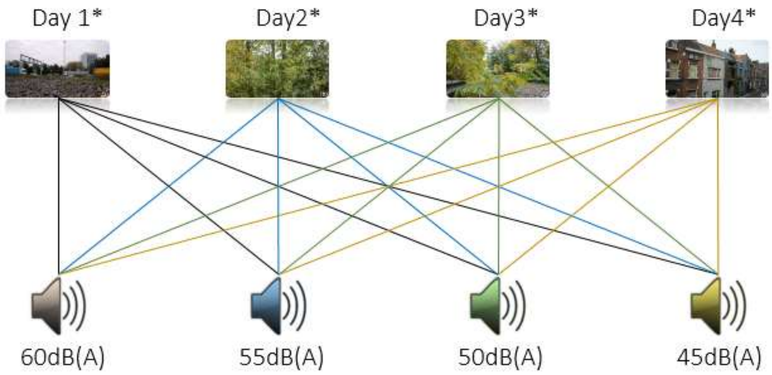


Figure 1 – 16 audiovisual stimuli (combination of 4 sound fragments and 4 window-view sceneries).
(*The order of experimental days was randomized)

The second part of the experiment was only conducted the fourth day, after the regular test was completed. It consisted of a listening task focused on detecting deviant auditory scenes. This was to avoid impact on the subsequent days. The second part also included the short version of the noise sensitivity questionnaire proposed by Weinstein [39].

2.2 Mockup living room

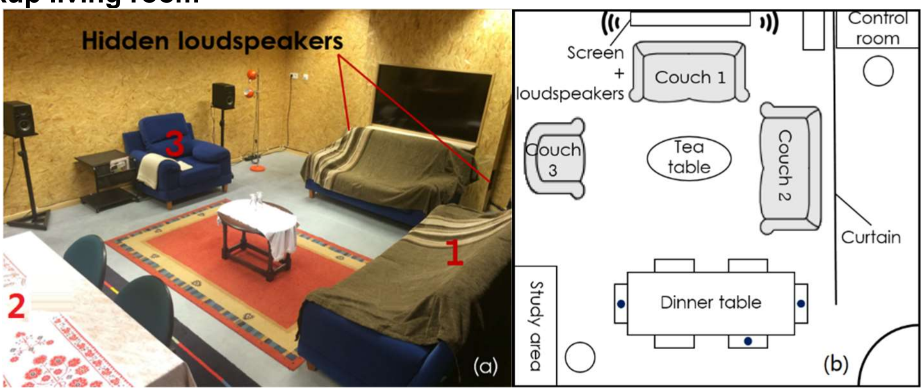


Figure 2 – Layout of the mockup living room: (a) photograph; (b) schematic drawing (not true to scale).

The mockup living room was arranged as shown in Figure 2. A 60-inch television screen, projecting window-view videos, was fixed in a specially-made cabinet integrating it in the wall and making it resemble a window. Two loudspeakers were hidden in the cabinet to make the sound appear to come from the window.. Note that the loudspeakers visible in Fig.2a were not used in this experiment. The control room is positioned in the corner, separated from the living room by a large thick curtain. A subwoofer is also positioned next to the control room, which ensures that low frequency sound is reproduced realistically.

As shown in Fig.2a, three sitting positions were marked in this room. Participants were suggested only to sit in these preselected seats, which gives them certain perspectives to the mock-up window (obviously, they are not being told that this was the reason).

2.3 Audiovisual stimuli

2.3.1 Window-view video sceneries

The four videos contained a mixture of different natural and man-made landscape elements. Four screenshots of the videos (all taken near the city of Ghent, Belgium) are shown in Figure 3. Scene (a) provides an open view of highway traffic and contains very few green elements; (b) allows vision on some parts of the highway through the woods; (c) contains a totally green visual setting; and (d) shows a row of houses along a non-busy street, hiding a highway from sight. The sound source was completely visible in scenery (a) and partly visible in scenery (b), while in (c) and (d) no sound source was visible. On the other hand, scenery (b) and (c) contained dominant natural elements, whereas scenery (a) and (d) contained mostly man-made elements.

Video (a) has been synchronized to the audio, video (b) is not but the highway view is rather limited so that individual – possibly loud – vehicles cannot be detected anyhow. For the last two videos, synchronization is not relevant.

Figure 3 – The four window-view sceneries used in the experiment.

2.3.2 Audio fragments

Four audio fragments with different sound level are created by simulating the effect of a change in the window's acoustic insulation. The original traffic noise audio fragment was recorded simultaneously with the video recording at the location of scene (a) (see Figure 3) with a B-field microphone, in a four-channel B-format. This audio recording was then transformed into a two-channel format using VVMic (Visual Virtual Microphone) 3.4. Two channels played back near the left and right of the window can still give a sense of movement of individual cars. By playing the sound from the loudspeakers behind the television screen/window, the sound spatialization of a common living room is achieved. This recording will represent the open-window sound exposure for the participants.

When presenting audiovisual information to the listener, it is important that the auditory and visual cues on source distance are congruent. Hence we opted for noise mitigation through window insulation to mimic sound level variation in this study, as this would keep the spectro-temporal variation of the traffic sound consistent with the visual distance. In addition, this gave a plausible reason to the participants why different noise levels had to be evaluated. According to the work of Tadeu and Mateus [40], three transmission loss curves were selected to represent a (closed) single glazed, a double glazed and a triple glazed window (specific choices: ‘single layer 8mm’, ‘double 8+4, d=10mm’, ‘triple 8+4+4, d1=100, d2=50’). The original audio recording was filtered accordingly using Sony Soundforge software to mimic the different closed window acoustic insulation spectra as shown in Figure 4.

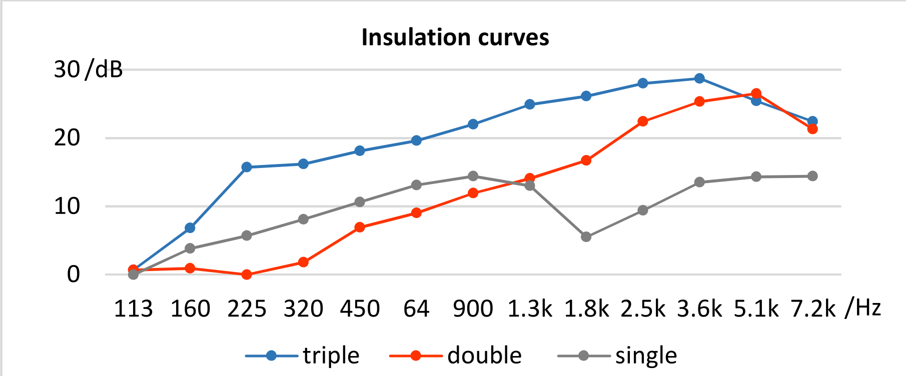


Figure 4 – Frequency attenuation (insulation curve after calculation).

By fixing the volume of the audio card of the playback PC, the media player software and the amplifier of the loudspeakers, the overall exposure sound level of the original audio fragment is settled at an equivalent sound pressure level of 60dB(A) (in the center of the room) for the assumed open window sound exposure. The overall presentation sound level for the single, double, and triple glazed is reduced towards 55dB(A), 50dB(A) and 45dB(A), respectively, to make sure a clear level difference would be detected.

Participants were told that these sounds correspond to four different window insulations. It is assumed that this method of presentation ensures that it does not direct a participant’s attention to differences in the view from the window. As the difference between the sounds is in fact not the main target of the investigation, the above procedure for generating the different sound excerpts only needs to suggest ecological validity so a more advanced calibration of the room response is not essential.

2.4 Course of the experiment

It was already mentioned that the order of presentation of the visual context should be randomized to avoid bias by habituation to the experimental conditions during the subsequent sessions. In addition, within one experimental session, the 4 sound environments are also presented in random order to decrease the bias that might be caused by the previous sound experience. There are A_4^4=24 possibilities for the order of video presentation over the four experiment days, and an equal number of 24 possibilities for the order of audio fragment presentation during each experimental day. To prevent large level differences between subsequent tests, the maximum change in sound level between subsequent fragments was limited to 10 dB(A). This reduced the number of possible sound presentation orders to 12. The sound order randomization is applied after the videos have been assigned randomly between experimental days by adhering to the following rules: each scene should be coupled two times with all 12 sound orders, and over all experiment days, all four scenes should have a different audio fragment order. This randomization ensures that all possibilities are covered, and is expected to eliminate any impact of order of presentation on the results.

Participants were told that the experiment is designed to study their disturbance by road traffic noise in a living room environment. All they had to do was relaxing as if they were in their own living room. They were allowed to read a book, browse a magazine, have some drinks, play with their phone to some extent, or even chat with the other participants. However, activities that require a high level of concentration, such as bringing work-related documents, was forbidden. This setting (1) is close to real life; and (2) prevents that participants would focus too much on listening to the sound. Note that although activity disturbance may be a cause of annoyance, this experiment was not designed to assess activity disturbance itself. This would require a more stringent task design and a different range of sound exposures.

In between the 10-minutes lasting exposures, there was a one minute break, during which every participant was asked a single question: 'Thinking about the last 10 minutes staying in this living room, which number from 0 to 10 best shows how much you were annoyed or not annoyed by the traffic noise?' [38].

2.5 Audiovisual aptitude and noise sensitivity assessment

It is known that the response to a retrospective annoyance question is only partly determined by the equivalent noise level. Individual differences in response have been related to human factors such as gender, age and noise sensitivity. As this research is focusing on the effect of the view from the window on reported noise annoyance, an additional personal factor labeled "audiovisual aptitude" is added. This factor measures how strongly the visual context influences the ability of a person to detect differences in the auditory scene and remember them. Section 3 will elaborate on the possible perceptual and psychological phenomena that could underlay this new factor. To measure "audiovisual aptitude", at the end of the 4th day of the above-described experiment, a second experiment is conducted. It contains four audiovisual scenarios, in which either the audio or visual parts was altered in a subtle way [41]. The experimental design consists of a deviant detection task where three alternatives are presented once for each trial. The deviant has to be detected when only sounds are presented and when sounds are presented in the presence of a visual distractor. This ecologically valid alternative to basic psychological stimuli is intended to investigate whether a person is more vision or audition oriented but also measures its sensitivity to inattentional deafness [42].

On the outcome of this experiment, two classification principles are applied: auditory resolution and visual distractibility. Auditory resolution distinguished between persons that make no errors on the blind listening test, i.e. they detect the deviant in each of the four cases. This allows to distinguish the careful listeners with good auditory memory that are able to detect even the smallest change. Visual distractibility distinguishes between the persons that do well on the blind listening test but get misled by the incongruent visual information and make at least one error in deviant detection in this case. In other words this group gets misled by the visual information. Hereby ,two human factors arise: auditory acuity and vision dominance [43]. More information on this experiment can be found in [41].

Finally, at the end of the complete experiment, after four days, a more elaborate questionnaire was presented to all participants to collect some personal information and more in-depth questions, including age, gender, education level and noise sensitivity, via a widely-used noise sensitivity survey [39]. In addition, the hearing status of all participants was assessed via pure tone audiometry (PTA) carried out in a quiet but not sound-proof room using a regularly calibrated AC5Clinical Computer Audiometer.

3. Results and Analysis

3.1 Participants

In total 75 participants conducted this experiment, 6 of them were excluded from the final dataset due to either bad hearing (based on a pure tone audiometric test performed on the 4th day), or not completing the full experiment. Basic demographic information is listed in Table1.

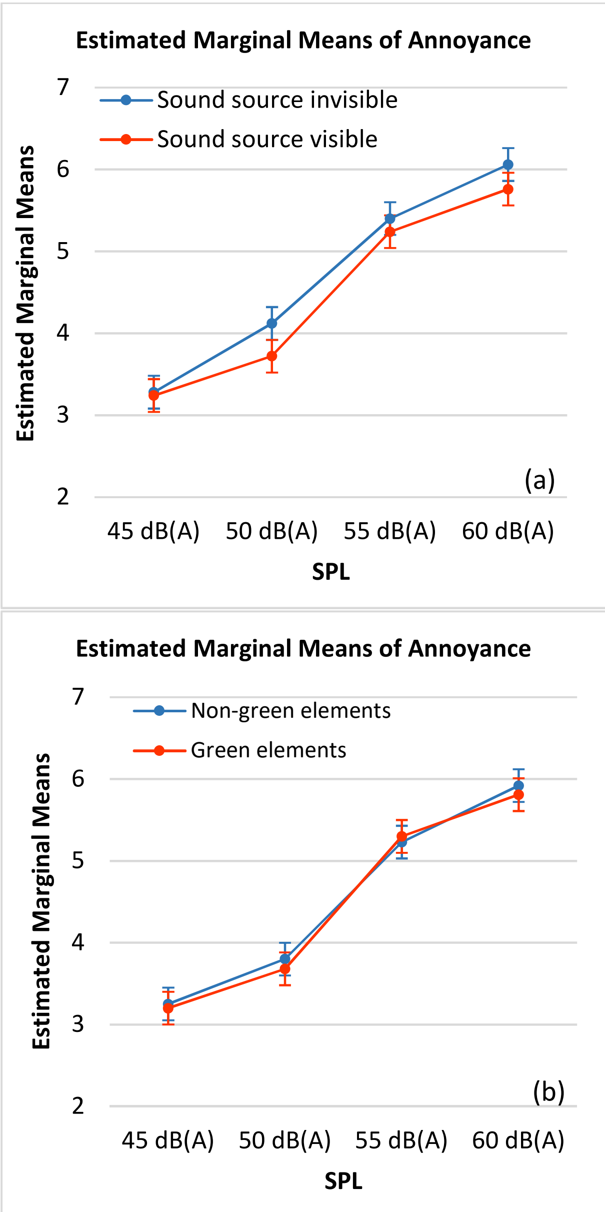
Table 1 – Basic information of 69 participants.

Factors	Categories	Number	Percentage/%
Gender	Female	28	40.6
	Male	41	59.4
Age*	Junior(20~27yrs)	37	53.6
	Senior(28~46yrs)	32	46.4
Education	Below M.S	20	29
	Above M.S	49	71

*The age variation of participants is from 20 to 46 yrs. The average value is 27.9 and the median value is 27.

3.2 Visual factors

As described in Section 1.2.1, the content of four window-views can be sorted based on two features: the visibility of sound source and the presence of green elements. In Figure 3, (b) and (c) contain dominating green elements, while (a) and (d) do not. On the other hand, in (a) and (b), the sound source (highway traffic) is visible, while in (c) and (d), it is not. Figure 5 indicates the difference of estimated marginal means of annoyance based on these two features.



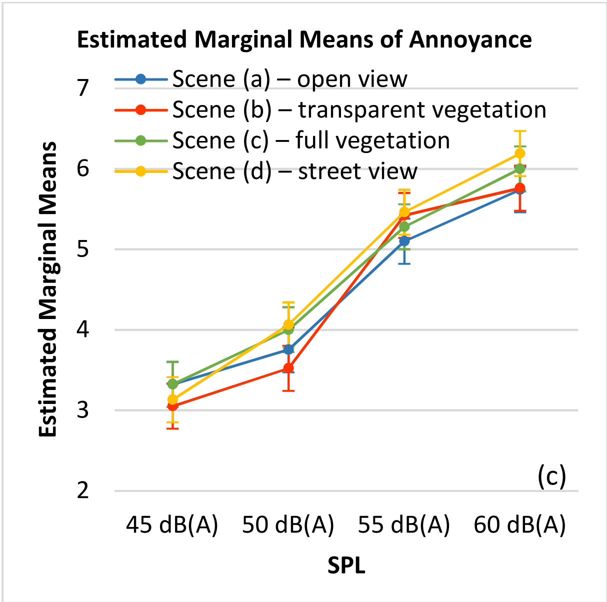


Figure 5 – The annoyance difference of (a) visibility of sound source, (b) visibility of green elements and (c) four window-view scenes.
(The error bars represent the standard errors on the averages: +/- 1SE)

As shown in Fig.5a, average reported noise annoyance increases strongly with the noise level, including the change in spectrum caused by the window insulation. It should be noted that different sound environments were presented during the same day and thus a direct comparison was possible. When looking at the influence of the window view, participants tend to be less annoyed when the sound source was visible (scenery (a) and (b)). Meanwhile, there is also a larger jump between low SPL and high SPL in this category (red line in Fig.5a). When the sound source is visible, people's annoyance tends to be divided into two stages for either low and high levels. At both the low and high levels, the annoyance increases with SPL are not as fast as when the sound source is invisible. Nevertheless, the annoyance-SPL regression tends to be more linear when the sound source is invisible. Visible green elements do not seem to have a large influence (Fig.5b) in this overall analysis.

As all experimental conditions have been assessed by each participant in the study, and personal factors are assumed to have a significant effect on the self-reported annoyance rating, two level statistics treating person as a random variable is appropriate. The different sound environments are characterized by their A-weighted sound level, but also differ in spectral characteristics. Therefore, SPL is treated as an ordinal variable for the exposure condition rather than as a continuous variable.

A mixed factor generalized linear model fit is applied, using participant as a random factor to generalize these results. This model considers only the sound (SPL) and the visual factor(s). For visual factor(s), it is tested with only the 4 views (sceneries) or with green elements visibility and sound source visibility as a descriptor of the window view. Besides, it is also tested to add the interaction between the sound and the visual factor(s) and to remove the insignificant factor(s). The best model (with the lowest information criterion) from the above-mentioned ones is listed in Table 2. The effect of sound source visibility on reported noise annoyance is statistically significant while the visibility of green elements is not. Also, none of the interactions between sound and visual factor(s) has statistical significance. However, as shown in Fig.5a, the relatively small difference between lines and the overlapping of standard error bars suggests that the significance of sound source visibility will be less pronounced as stronger factors get involved in the model.

Table 2 – Generalized linear model 1.

Fixed Effects	Target: Annoyance

Source	F	df1	df2	Sig.
Intercept	178.129	4	1.099	.000
Sound source	7.493	1	1.099	.006
SPL	235.008	3	1.099	.000

*'Participant' is used as random factor.

3.3 Human factors

A frequently mentioned personal factor, noise sensitivity, is investigated in this study. The post-processing divided participants into two groups based on the neutral score, i.e. choosing the neutral answer for each single question in Weinstein's questionnaire [48]. In total, 57 participants obtained a score higher than the neutral score, which leads them to be marked as being highly sensitive to noise, whereas all others are categorized as having low noise sensitivity. As shown in Figure 6, people with high sensitivity are clearly much more annoyed than people with low sensitivity.

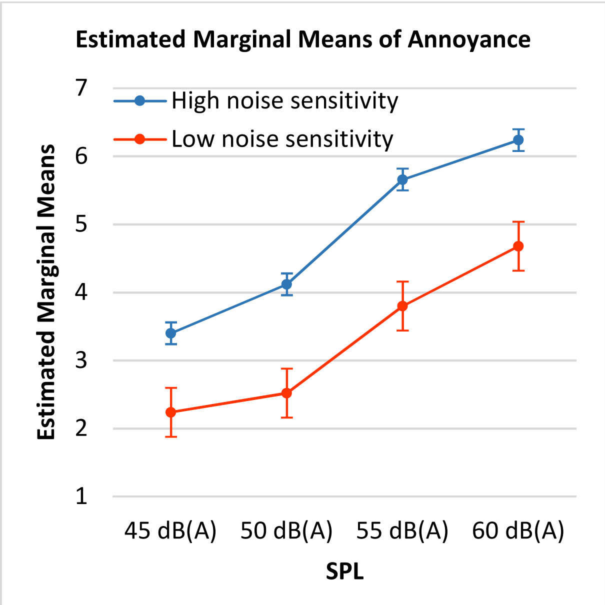


Figure 6 – Dependence of reported noise annoyance on exposure for different sensitivity categories. (The error bars represent standard errors on the averages: +/- 1SE)

As mentioned in Section 1.4, participants are clustered according to their audiovisual aptitude along two dimensions: auditory acuity and being vision dominated. Fig.7a shows that participants with good auditory acuity (30 participants) are less annoyed than others. The second factor selects the group labeled vision dominated (13 participants). They have good auditory acuity but are easily distracted by incongruent visual stimuli. These vision dominated participants are notably less annoyed than the other 56 participants, as shown in Fig.7b.

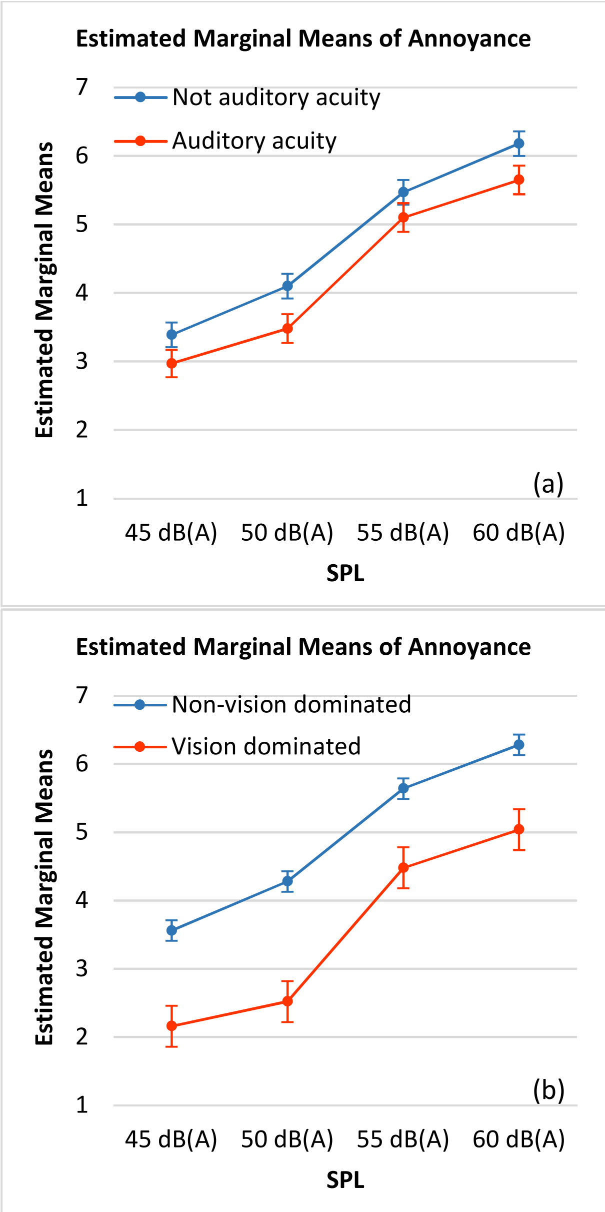


Figure 7 – Reported noise annoyance as a function of exposure differentiated according to (a) auditory acuity and (b) being vision dominated.
(The error bars represent standard errors on the averages: +/- 1SE)

To test the significance of these human factors, a generalized linear model focusing on the human factors is constructed. Still, participant is used as a random factor to generalize the current results. For visual factor(s) in this model, it is tested with only the 4 views (sceneries) or with green elements visibility and sound source visibility. Similar to model 1, it is also tested to remove the insignificant factors. The best model (with the lowest information criterion) is shown in Table 3. As can be seen, sensitivity and being vision dominated are statistically significant whereas auditory acuity is not. This indicates (1) the importance of noise sensitivity as a human factor; (2) the limitation of auditory acuity by purely focusing on auditory resolution; and (3) the potential influence of being vision dominated on perception.

Table 3 – Generalized linear model 2.

Fixed Effects	Target: Annoyance			
Source	F	df1	df2	Sig.

Intercept	66.779	11	1.091	.000
Gender	2.374	1	1.091	.124
Education level	0.901	1	1.091	.343
Age	2.791	1	1.091	.095
Sensitivity	5.803	1	1.091	.016
Auditory acuity	0.019	1	1.091	.889
Vision dominated	4.021	1	1.091	.045
SPL	234.860	3	1.091	.000
Green	0.349	1	1.091	.555
Sound source	7.488	1	1.091	.006

*'Participant' is used as random factor.

3.4 Interaction between personal factors and window view

In the generalized linear models derived above (Table 2 and Table 3), personal factors and window view are treated as independent factors. The goal of this study is nevertheless to detect the personal factors that can affect the influence of window view on perceived noise annoyance. Therefore, a generalized linear model is fitted that includes interactions, especially interactions between above mentioned human factors and visual factors.

Table 4 shows all the variables mentioned in this study. Individually, many of them showed statistical significance in models for noise annoyance. However, since more variables are involved, some of them are no longer statistically significant due to the strong effect of the interactions. In the human factors category, sensitivity and being vision dominated remain influential factors. On the other hand, descriptors of the view from the window are no longer statistically significant.

Table 4 – Generalized linear model 3.

Fixed Effects	Target: Annoyance			
Source	F	df1	df2	Sig.
Intercept	50.283	15	1.087	.000
Gender	2.438	1	1.087	.119
Education level	0.925	1	1.087	.336
Age	2.866	1	1.087	.091
Sensitivity	5.960	1	1.087	.015
Auditory acuity	0.020	1	1.087	.888
Vision dominated	4.129	1	1.087	.042
SPL	236.894	3	1.087	.000
Green	2.254	1	1.087	.134
Sound source	0.352	1	1.087	.553
Sensitivity*Green	1.610	1	1.087	.205
Sensitivity*Sound source	5.941	1	1.087	.015
Vision dominated *Green	4.894	1	1.087	.027
Vision dominated *Sound source	0.098	1	1.087	.754

*'Participant' is used as random factor.

The results also involve the interaction between visual factors and two human factors: sensitivity and being vision dominated, which remain statistical significant in the model with interactions. Two out of the four interactions are statistically significant in model 3. The first one is the interaction between noise sensitivity and sound source visibility (Fig.8a). This interaction supports two observations: (1) The dependence of noise annoyance on noise sensitivity increases when the sound source is not visible; (2) For noise sensitive people, sound source visibility decreases annoyance while for noise insensitive people sound source visibility slightly increases annoyance.

The second statistically significant interaction is the one between being vision dominated and green element visibility (Fig.8b). In this study, the visibility of green elements in the window view averaged over all participants does not have a statistically significant influence on reported noise annoyance. For vision dominated persons the visibility of green elements increases noise annoyance. For the remainder of the participants, there is nearly no effect of visibility of green elements in the window view.

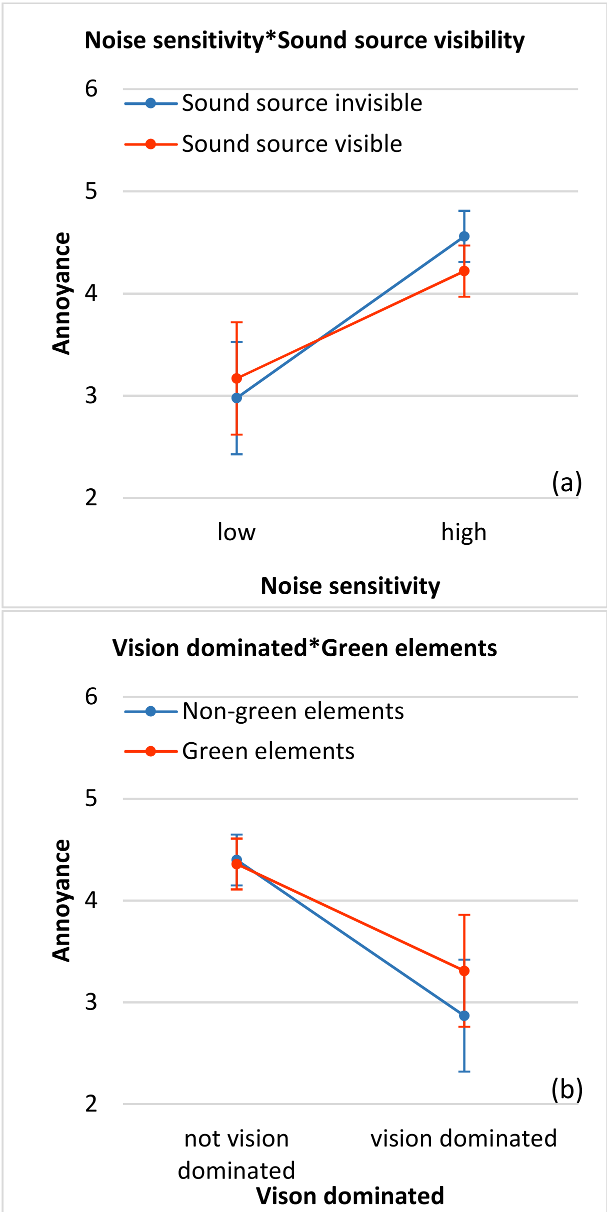


Figure 8 – The interaction between (a) sensitivity and sound source visibility and (b) being vision dominated and green elements visibility.
(The error bars represent the standard errors on the averages: +/- 1SE)

4. Discussion

A laboratory experiment was designed to increase our understanding of the mechanisms governing the effect of the window view on perceived noise annoyance. In particular, the experiment aimed at uncovering effects that may occur during processing of audiovisual stimuli. With these goals in mind, the experiment was designed to minimize influences of reasoning and general context setting by the visual elements. Thus, the aim was to avoid that test participants would consider living in a higher quality neighborhood based on the view from the window. Amongst others, the views were therefore chosen not to be particularly attractive gardens or landscapes. As preceding experience and the duration of the tests may influence the annoyance response, auditory stimuli were presented in random order during one test day and visual context was changed in random order between experimental days. The large number of possibilities combined with a limited number of participants resulted in the fact that some particular orders were presented to a single participant only. An ANOVA test checking the influence of stimuli orders showed no statistical significant ($p>0.05$) effect. Therefore, this randomization of the presentation order was shown to have no effect.

This study derived three generalized linear models, considering visual factors, human factors and interactions in addition to sound as independent variables. The information criterion indicators, estimators of the relative quality of statistical models, of these three models are shown in Table 5. A lower information criterion value indicates a better quality of the model. The first model introduces information on the view from the window. Model 2 shows that adding personal information improves the predictability of reported noise annoyance. Finally, model 3 emphasizes that the interaction between these personal factors and the view from the window might explain the inconsistent evidence of the impact of window view on reported noise annoyance.

Table 5 – Comparison between three generalized linear models

		Model 0 (sound only)	Model 1 (visual factors)	Model 2 (person factors)	Model 3 (person-visual interaction)
Information Criterion*	Akaike Corrected	4088	4083	4036	4028
	Bayesian	4103	4098	4051	4043

* Models with smaller information criterion values fit better.

Concerning the direct impact of view from the window (model 1), it was shown that adding the four views separately did not result in any improvement of the model in terms of Akaike information criterion (AIC) or Bayesian information criterion (BIC). Entering the presence of green and the visibility of the source as separate variables resulted in a slight improvement, but only the visibility of the source had an effect. Moreover, adding interaction effects between sound level and window view, which might have been expected on the basis of Figure 5, did not improve the model. Table 2 shows that sound source visibility has statistical significance and thereby confirms previous audiovisual experiments [28]. Figure 5a further shows that people tend to be less annoyed when the sound source is visible. However, some early research on sound source visibility [24] pointed out that hiding the sound source from sight would reduce annoyance for students in a classroom setting. The current finding is consistent with more recent research [43] putting forward the hypothesis that people tend to be more anxious when a moving sound source cannot be seen. Expectation and attention focusing could be a potential explanation for these – at first sight – contradictory findings. In a situation with a sound-irrelevant task requiring high concentration, like for instance following courses in a classroom, the noise distracts attention from the primary task and is against people's expectations; adding congruent visual information will increase audiovisual saliency and will worsen this situation. In situations where people's attention is mainly led by the noise – as in the current experiment – introducing visual information matches people's expectation and therefore could slightly lower annoyance.

Another conclusion that can be drawn from model 1 is the limited importance of visible green elements (Fig.5b). Yet, visible green typically tends to be positive in many soundscape studies [18][45]. Van Renterghem and Botteldooren [17] pointed out that a green window view significantly reduces self-reported noise annoyance at home, and this effect becomes stronger with an increasing percentage of green elements in the window plane. In real-life settings, a green window view does not only stand on itself, but also delivers information on the general quality of neighborhood or the presence of appealing green areas nearby, both factors that were shown to influence reported noise annoyance. This study, however, was designed not to contain such information, as it is conducted in an underground lab with artificial outside view, and the chosen views accounts for the limited space between the window and a highway. The green scenes in this study essentially hide the source and do not suggest the presence of a park or green area.

Among the human factors introduced in model 2, noise sensitivity has a strong impact, consistent with many studies using the same method of measuring self-reported sensitivity [46]. More importantly, the refined assessment of individual audiovisual aptitude gives strong proof of the visual distraction hypothesis. Vision dominated individuals tend to be less annoyed at the same noise level (Figure 7). The personal factor being vision dominated has a high significance in model 2. A small effect of auditory acuity is also seen in Figure 7, but this effect does not statistically significantly contribute to model 2. It is interesting to note that other personal factors like gender, age or education level do not statistically significantly contribute to the model. The effect of these factors may be captured by noise sensitivity and being vision dominated. Additionally, the result also indicates that the methodology of determining these two factors, through audiovisual aptitude investigation, is reliable.

The model with interactions (model 3, Table 4) gives a balanced view on the influence of visual factors, expectations and congruence of audio and visual information. The model improvement caused by adding the interactions exceeds the improvement by adding information on window view without taking personal factors into account. Two interactions are observed. The first statistically significant interaction is between sound source visibility and noise sensitivity (Fig.8a). This interaction indicates, on the one hand, that highly noise sensitive people are notably more annoyed when the sound source is invisible. Scenarios with invisible sound sources do not match the soundscape and this may give highly noise sensitive persons a feeling of insecurity, intensifying noise annoyance. On the other hand, people with low noise sensitivity are less likely to notice the environmental noise. Visible noise sources increase the probability that these persons notice the traffic sound and get annoyed by it. People implicitly express their general attitude towards noise by their sensitivity. High noise sensitivity may also indicate more awareness of the environment in general. They expect the visual to match the audio information. Hence, when the sound source is visible, the satisfaction of getting their expectations fulfilled would decrease annoyance by noise. Finally, it can be noted that this observation also matches the discussion in the previous paragraphs stating that the effect of visibility of the source may depend on the context, where visibility of the source reduces annoyance in a context that stimulates listening. Noise sensitive persons are more likely to be listening.

The second significant interaction is between vision domination and green element visibility (Fig.8b). For non-vision dominated persons, the presence of green in the visual scene does not affect their annoyance rating. Vision dominated persons, however, report higher annoyance when the window view contains the almost impervious green elements as used in the current research. This may imply that these persons are shaping their expectations based on the visual scene rather than to rate noise annoyance based on the noise alone. Interestingly, experimental results involving incongruence of visual and audio information are the direct reasons for these people to be identified as being vision dominated, as described in section 1.4. Furthermore, the larger difference caused by green elements visibility in vision dominated people shows their greater concern about the visual information, compared to non-vision dominated people.

Audiovisual aptitude, the new factor that was shown in these experiments to explain at least partly the variance in effects of window view on self-reported noise annoyance, is a feature that is orthogonal to noise sensitivity. This could be shown by the lack of correlation between these two factors. However, there is also a clear underlying reason for this. According to Soames Job [47], noise sensitivity includes factors such as “level of physiological reactivity to stimulation generally; hearing acuity; attitudes to noise in general; beliefs about harmful effects of noise in general; vulnerability caused by stressors other than noise; level of social support and other available coping mechanisms.” It is thus a much wider concept than audiovisual aptitude that measures a person’s sensory capability of perceiving increasingly subtle elements of the soundscape. Though annoyance is an outcome of many combined mechanisms, the inner willingness to perceive and pay attention to the soundscape seems relatively more important than the capability. The reader should however bear in mind that the similarity between rating scales for sensitivity and annoyance could also reveal an underlying similarity in rating behavior, which is not present in the deviant detection test used to rate audiovisual aptitude.

5. **Conclusion**

In this study an ecologically valid experiment was performed in which a series of audiovisual stimuli were presented in a mock-up living room with the goal to create a better understanding of the influence of window view on reported noise annoyance. Regarding visual factors, sound source visibility was shown to have more impact than green element visibility on self-reported annoyance. Regarding human factors, noise sensitivity was found to have the strongest statistical significant effect on annoyance. A specially designed audiovisual aptitude assessment exposed two reliable human factors, which were shown to explain the large variation in effects of window view on noise annoyance. The results of the experiment validate hypotheses on the role of expectations and multi-sensory attention in perception and appraisal of the sound environment.

Although the noise itself obviously is the dominating factor in the emergence of noise annoyance, it only explains a limited part of the variance. Hence, it is essential to study other factors involved which have the potential for becoming noise mitigation measures. Visibility of the source and a green window view have been mentioned as environmental modifiers of the noise exposure annoyance relationship, yet evidence has been inconclusive. In the present noise annoyance experiment, it was found that the effect of being a vision dominated listener is almost as significant as the effect of noise sensitivity – a known stable personality trait – but more importantly, this personal factor interacts with visual factors. This factor should therefore be considered in future investigations.

A number of limiting factors can be identified with the design of the current experiment. E.g. participants were asked to participate on 4 separate days, with the goal to erase their auditory memory. Still, it is impossible to assure that participants are in the same mood on each of the experimental days. Since this study is on audiovisual perception, one can expect that the mental status and mood of the participants has an effect on the results. Next to this, human factors and visual factors are investigated in this study, yet the acoustical properties of the stimuli are only described in terms of sound pressure level. In many sound quality studies, it has been shown that other features such as frequency and temporal content, sharpness and loudness also change people’s preference towards sounds. However, in this study, the precise psychoacoustical characteristics of the sounds were not the essential targets, as the main goal was to study audiovisual interaction.

The visual factors, personal factors and interactions identified in this work help to understand the mechanisms underlying the emergence of noise annoyance. The audiovisual aptitude factor that was introduced in this study could be applied in audiovisual studies as an extended personal factor next to noise sensitivity. The experiment used for assessing audiovisual aptitude is not easily transferrable to field interviews and may benefit from being replaced by more suitable tests or questionnaires for this purpose. The interactions also may have consequences on the design of acoustic and visual elements in urban soundscapes. For this, audiovisual aptitude should be related to demographic variables, lifestyle, and context to allow to identify the most vulnerable groups. Two practical implications of recognizing the existence of a personal factor that affects the influence of visual setting on noise annoyance could be identified. Firstly, it constitutes a warning that noise annoyance mitigation that would be based on changing visual context may not work for all subpopulations (with different audiovisual aptitude) in the same way. Secondly, urban sound planners may opt for a worst case approach that leads to acceptable perception of the living environment also for the most noise sensitive people and those that are not vision dominated.

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