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How do audio and visual characteristics of wind turbines contribute to noise annoyance?

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ABSTRACT

Wind farms often evoke strong annoyance reactions in residents. Literature suggests that both acoustical characteristics and the visibility of wind turbines may contribute to noise annoyance. However, studies on the mutual audio-visual effects on annoyance are still rare. The objective of this study was to investigate the short-term noise annoyance reactions to different wind turbine noise situations in a controlled laboratory experiment. A set of 24 audio-visual rural scenarios containing a single wind turbine was synthesized, i.e., visualized and auralized. Combined with the full factorial experimental design, this allowed separating the individual contributions of the following variables to noise annoyance: distance to the wind turbine, periodic amplitude modulation of the sound (with, without) and visual setting (landscape with or without wind turbine; grey background). The experiment revealed that both visual and acoustical characteristics strongly affect noise annoyance. Annoyance increased with periodic amplitude modulation and/or decreased when a landscape was visible. For the latter case, the visibility of a wind turbine increased annoyance. While the acoustical effects could be reliably assessed, the visual effects were less straightforward to reveal, as they are afflicted with carryover effects. The presentation order of audio-visual stimuli was therefore found to be crucial for study outcomes.

Keywords: Wind turbine noise, Noise annoyance, Audio-visual effects

1. INTRODUCTION

Wind farms often evoke strong annoyance reactions in residents at comparably low sound pressure levels, more so than other sources such as transportation noise (1). The visual as well as acoustical impacts of wind farms have therefore recently been much discussed. Literature suggests that both acoustical characteristics (e.g., (2)) and the visibility of wind turbines (e.g., (3)) may contribute to noise annoyance. However, studies on the mutual audio-visual effects on annoyance are still relatively rare. Only in recent years, such studies were conducted (e.g., (4, 5)). They confirmed that indeed both acoustical characteristics and visual impacts of wind farms contribute to (noise) annoyance.

When performing experiments on audio-visual effects, one should also consider the presentation order of the stimuli. The latter may strongly affect the results due to two serial position effects: simple order effects and/or differential carryover effects (6). While simple order effects can be averaged out by counterbalancing, carryover effects cannot. Here, other strategies such as sufficiently long time intervals between presented stimuli need to be applied. To date, however, studies on audio-visual effects did not systematically consider these two serial position effects.

The objective of this study therefore was to investigate the short-term noise annoyance reactions to different wind turbine (WT) noise situations in a controlled laboratory experiment, considering also possible serial position effects.

This study has already been published in the journal “Landscape and Urban Planning”, and all study details may be found there (7).

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2. METHODS

A set of 24 audio-visual scenarios with a single WT was synthesized, i.e., visualized and auralized. Combined with the full factorial design of the experiment, this allowed separating the contributions of the following variables to noise annoyance: observer distance to the WT, periodic amplitude modulation (AM) of the sound (no, with), and visual setting (landscape with WT, landscape without WT, grey background) (Table 1). For the cases with landscape, the same rural, hilly landscape was chosen for both situations, with and without WT. For the case without landscape (which is a typical setting in classical psychoacoustic experiments with acoustical stimuli only), a grey background was chosen (Table 1).

Table 1 – Factorial design of the experiment with audio-visual wind turbine (WT) stimuli covering observer distances to the WT of 100–600 m, two situations of periodic amplitude modulation (“no”, “with”), and three visual settings. The table shows the resulting A-weighted equivalent continuous sound pressure levels (L_{Aeq}) in dB per variable combination.

Distance to WT [m]	Visual setting					
	Landscape with WT		Landscape without WT		Grey background	
	Amplitude Modulation					
	no	with	no	with	no	with
100	48.6	49.4	48.6	49.4	48.6	49.4
200	43.6	44.6	43.6	44.6	43.6	44.6
350	38.2	39.2	38.2	39.2	38.2	39.2
600	33.0	34.0	33.0	34.0	33.0	34.0

The visualization was created using the game engine CRYENGINE (https://www.cryengine.com) as described in (8). The auralization was done with the sound synthesis models described in (9, 10). The resulting videos and audio data were time synchronized and linked as described in (8).

Forty-three subjects (22 females, 21 males) participated in the study. The laboratory experiments were conducted in the "Mobile Visual-Acoustic Lab" (MVAL) (11) at the authors' institution ETH Zurich. The experimental procedure largely followed the description in (2). In the experiments, the subjects attentively watched and listened to the simulations and rated each stimulus after playback regarding noise annoyance using the ICBEN 11-point scale (12).

A preliminary experiment to this study revealed that the visual (but not the acoustical) effects were afflicted by differential carryover effects. Therefore, the three visual settings were presented in three blocks in completely counterbalanced order, while the 8 acoustical situations per block were presented in randomized order. With this design, the visual settings of the first block (first 8 stimuli) are free from potential carryover effects, while only the subsequent two blocks (remaining 16 stimuli) may contain such effects.

The resulting data set was first visualized, and subsequently analyzed with linear mixed-effects models (procedure MIXED of IBM SPSS Version 23 and 25).

3. RESULTS AND DISCUSSION

Figures 1 and 2 present boxplots of the individual annoyance ratings, showing the median (50%, horizontal line in boxes), the first and third quantiles (25% and 75%, lower and upper boundaries of boxes), the whiskers (data within 1.5 times the interquartile range), and outliers (outside the whiskers).

The acoustical characteristics strongly affect noise annoyance (Figure 1). For the first block of visual setting, noise annoyance strongly increases with the A-weighted equivalent continuous sound pressure level (L_{Aeq}) and is larger in situations with AM compared to situations without AM (Figure 1a). In fact, AM led to an annoyance increase of ~0.6 units on the 11-point scale, which would also be evoked by an equivalent sound level increase of ~2 dB. This corroborates the findings of (2). The effects revealed by the whole set of 24 stimuli (Figure 1b) are very similar to those of the first block, except that the annoyance ratings tend to be higher. Apparently, the subjects became increasingly annoyed by the stimuli over the experiment. This indicates a simple order effect, as was also observed in (2).

Also the visual setting is important for noise annoyance (Figure 2). For the first block of visual setting (free from potential differential carryover effects), noise annoyance decreases in the order grey background > landscape with WT > landscape without WT. Compared to the landscape without visible WT, WT visibility led to an annoyance increase of ~0.7 points on the 11-point scale. This corresponds to an equivalent sound level increase of ~2 dB (i.e., similar as for AM). Thus, a visible WT was linked to increased annoyance, which is in line with literature (3). The visible WT may have drawn the focus of the subjects to the WT noise, while the subjects were more distracted by the landscape without WT. Similarly, the grey background may be associated with the highest annoyance because it did not allow for any (visual) distraction from the noise. Contrary to the quite stable acoustical effects, the visual effects of the first block were completely lost over the whole experiment (Figure 1b). Here, the three settings were linked to very similar annoyance reactions. This may be attributed to a differential carryover effect. It cannot be eliminated by counterbalancing, but must be dealt with using other strategies such as sufficiently long time intervals between stimuli.

The above observations were all corroborated with mixed-effects models.

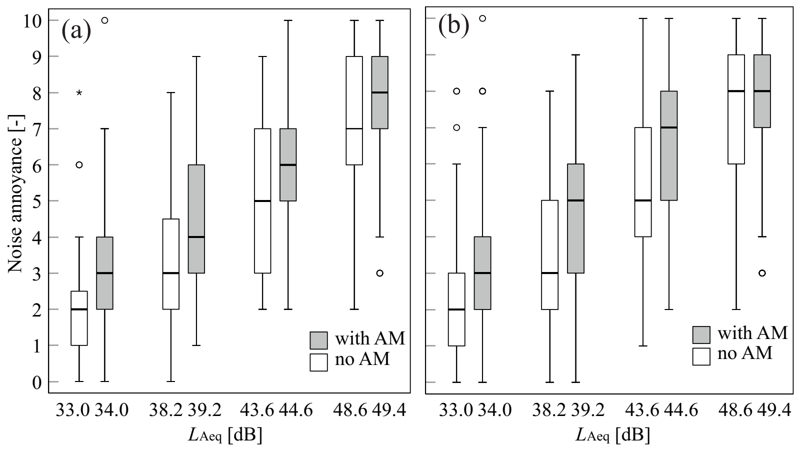

Figure 1 – Boxplots of the individual noise annoyance ratings as a function of the A-weighted equivalent continuous sound pressure level (L_{Aeq}) and amplitude modulation (no or with AM), (a) for the first block (first 8 stimuli) and (b) all three blocks of visual settings (24 stimuli). Note that the x-axis is not to scale.

4. CONCLUSIONS

The present study revealed that both visual and acoustical characteristics strongly of WTs affect noise annoyance in a laboratory setup. In particular, annoyance increased with periodic AM and/or decreased when a landscape was visible. For the latter case, the visibility of a WT led to an annoyance increase corresponding to an equivalent sound level increase of 2 dB. While the acoustical effects could be reliably assessed, the visual effects were less straightforward to reveal, as they were afflicted with carryover effects. The presentation order of audio-visual stimuli was therefore found to be crucial for study outcomes.

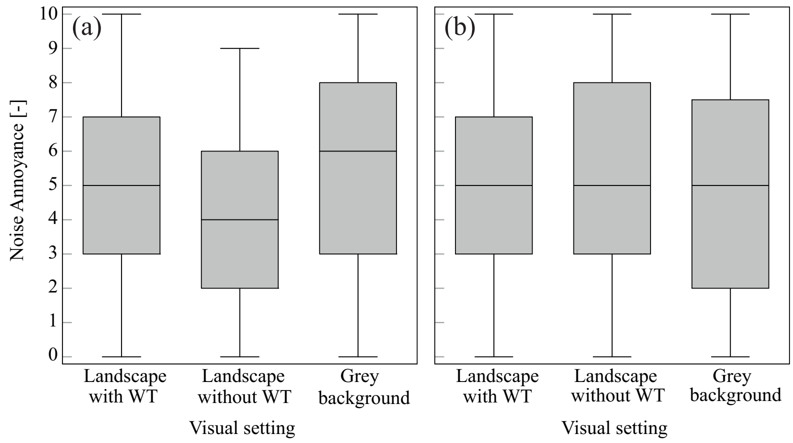

Figure 2 –Boxplots of the individual noise annoyance ratings as a function of the visual setting, (a) for the first block (first 8 stimuli) and (b) all three blocks of visual settings (24 stimuli).

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FULL PUBLICATION

This study has already been published in the journal "Landscape and Urban Planning", DOI 10.1016/j.landurbplan.2019.01.014, and all study details may be found there (7).

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