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Journal of Environmental Psychology 28 (2008) 379–389

Journal of ENVIRONMENTAL PSYCHOLOGY

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# The impact of visual factors on noise annoyance among people living in the vicinity of wind turbines

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## Abstract

Wind turbines are highly visible objects and the response to wind turbine noise is possibly influenced by visual factors. In this study, visibility of the noise source, visual attitude and vertical visual angle (VVA) in different landscapes were explored. Data from two cross-sectional field studies carried out among people living near wind turbines ($n = 1095$) were used for structural equation modelling. A proposed model of the influence of visual attitude on noise annoyance, also comprising the influence of noise level and general attitude, was tested among respondents who could see vs. respondents who could not see wind turbines from their homes, living in flat vs. hilly/rocky terrain, and living in built-up vs. rural areas. Visual attitude towards the noise source was associated with noise annoyance to different degrees in different situations. A negative visual attitude, more than multi-modal effects between auditory and visual stimulation, enhanced the risk for noise annoyance and possibly also prevented psychophysiological restoration possibilities. Aesthetic evaluations of the noise source should be taken into account when exploring response to environmental noise.

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## 1. Introduction

Community noise is an increasing environmental problem known to cause adverse health effects (Berglund & Lindvall, 1995). Large efforts have been made to define dose–response relationships between sound level and the frequency of annoyance (as a measure of impairment) in order to form a base for noise regulations. It is however apparent that different noise sources have different impact on people living in the vicinity of the sources, despite sound levels. For example, noise from aircraft is more annoying than road traffic noise, which in turn is more annoying than noise from rail roads (Miedema & Voss, 1998). Several factors related to the source, the receiver and the context in which the noise is perceived moderate the dose–response relationship. There is therefore a need to study such moderating effects for several community noise sources.

Wind turbines are new sources of community noise and their impact on people living nearby are as yet only partly known. In order to initially describe the response to wind turbine noise, cross-sectional studies in 12 different areas in Sweden were carried out (Pedersen & Persson Waye, 2004, 2007). Dose–response relationships between A-weighted sound pressure levels (SPLs) and noise annoyance with wind turbine noise were verified in these studies, even though the noise levels from wind turbines were low, typically being below 40 A-weighted decibel (dB(A)) outside the dwellings of respondents (Pedersen & Persson Waye, 2004, 2007). The impact of the sound levels on noise annoyance varied between study areas, and the variance in noise annoyance between individuals was not fully explained. During these studies it became apparent that the visual impact of the wind turbines interacts with the response to wind turbine noise. In an interview study with people living in the proximity of wind turbines the interviewees talked primarily about the noise, but also about the spoiled view and the constant movement of the rotor blades always attracting the eyes (Pedersen, Hallberg, & Persson Waye, 2007).

Wind turbines are often placed in a rural landscape where they are highly visible and for this reason, people exposed to wind turbine noise in their home environment

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doi:10.1016/j.jenvp.2008.02.009

could be expected to also receive visual stimuli from the same source. The consequences of this multiple sensory exposure are not known. The interaction between noise and vision from other sources in the environment has, however, been studied, using a global perspective to investigate the interaction between environmental noise and vision, the influence of noise on vision, and the influence of vision on noise, as described by Viollon, Lavandier, and Drake (2002), who also emphasized the importance of declaring such a perspective.

Our interest is the influence of vision on the response to the auditory stimuli, which has previously been studied mainly with regard to road traffic noise. Several results of these studies could be relevant also to wind turbines. Seeing the noise source has been found to increase noise annoyance. In a field study carried out in a Chinese city park where a school was situated, a heavily trafficked road (the noise source) was visible for some of the visitors in the park and students/teachers in the school while for some it was blocked by hedges (Bangjun, Lili, & Guoqing, 2003). At the same sound level the probability of noise annoyance was significantly higher if the noise source could be seen than if it could not be seen.

The effect of the sound source being visible is, however, not always clear. In an experimental study by Aylor and Marks (1976), listeners were instructed to compare the relative loudness of a noise transmitted through barriers of different solidity. Loudness was judged to be lower when there was a barrier partially obscuring the sound source than when there was no barrier, but greater when the sound source was totally obscured. The latter was an unexpected finding and the authors discuss the possibility that when a sound source is totally obscured, one expects its loudness to be diminished (Aylor & Marks, 1976).

A reduction in noise annoyance due to a positively evaluated visual appearance has furthermore been observed. In a field laboratory study, subjects evaluating annoyance due to traffic noise were less annoyed if a slide of a visually attractive street was presented together with the noise as compared with the same noise level presented together with a visually unattractive street (Kastka & Hangartner, 1986). The same tendency was found in an experimental study where subjects were exposed to five visual settings of varying degrees of urbanization and eight urban sounds (Viollon et al., 2002). The more urbanized the visual stimulus, the more negative were the sound ratings, both for traffic noise and for a natural sound like bird song. In a later study, the influence of the visual appearance of noise barriers on auditory judgment was examined (Viollon & Lavandier, 2002). Consistently, it was found that the more pleasant the noise barrier, the less stressful the road traffic noise was perceived to be. The authors conclude that it is not just the design of the noise barrier, but the noise barrier as part of the landscape, that is beneficial for the response to the noise. The above reviewed findings led to the hypothesis that seeing wind turbines and hearing the noise simultaneously increases the probability of noise annoyance. Furthermore, positively evaluating the visual appearance of wind turbines would possibly decrease annoyance.

The visual evaluation described above is not easily understood, but could be part of an overall attitude towards the noise source; a factor well known to interfere with the response to noise. In a review of 12 studies regarding noise from traffic and rifle ranges, Job (1988) found that the mean correlation between attitude towards the noise source and noise response was 0.41, with a wide range of 0.20–0.78, however. Not only did the studies differ with respect to noise sources, but the definition of attitude towards the source also differed between the studies. Attitude is often measured as fear of the noise source (Fields, 1993; Miedema & Vos, 1999) and sometimes also includes noise sensitivity, even if this is more commonly studied as a factor of its own. However, Guski (1999) has discussed overall attitude as a distinct factor explaining the variance in evaluation of the source between individuals. Whether this attitude includes a visual aspect has not been clarified.

In our studies we have found that wind turbines are sometimes perceived as intruders (Pedersen et al., 2007), a feeling possibly enhanced when the wind turbines are tall and situated close to a dwelling. In a Danish study the height and closeness of a turbine, measured as the vertical visual angle (VVA), was found to better predict noise annoyance than the calculated noise levels (Pedersen & Nielsen, 1994). The correlation between VVA and noise annoyance could possibly be explained by a larger angle leading to an enhanced feeling of intrusiveness. The correlation could also be due to a more negative evaluation of the appearance of wind turbines as vertical objects in a horizontal (flat) landscape, as in Denmark, if the wind turbines are larger and placed closer to the dwelling of the respondent. The influence of VVA on noise annoyance should therefore be tested in other environments.

The aim of the present study was to explore the influence of visual factors on response to noise. Visual factors include visibility of the noise source, the visual aspect of attitude towards the noise source, the VVA, the vertical shape of the noise source contrasting with the flat landscape and the technical appearance of the noise source contrasting with a rural surrounding.

## 2. Theoretical model

The visual factors that were to be explored could be predicted to interact with each other and with the response to noise. They should therefore not be studied singly. Furthermore, attitude is a presumed factor of influence on the response to noise, which is not easily captured by a single measurement. General attitude towards the source is not distinct from attitude based on visual perception. There was therefore a need to develop a theoretical model. The model was tested with structural equation modelling (SEM) allowing theoretical constructs, i.e. latent variables in which unreliability of the indicators is acknowledged and measurement error is included in the equations. In order to examine the potential impact of visibility of the noise source, two-group modelling was performed, with the model being tested among respondents who could see at least one wind turbine from their home vs. respondents who could not. To explore the influence of landscape, the model was also tested among those living in flat terrain (Fig. 1) and those living in hilly/rocky terrain (Fig. 2) as well as among respondents living in built-up areas (suburbs or small villages) and those living in rural areas with a low population density. The VVA was not included in the model owing to a strong correlation with the noise exposure; instead, VVA was explored with multiple linear regression.

The proposed structural model is presented in Fig. 3. This model consists of the independent variable noise level (manifest variable) and visual and general attitude towards wind turbines (latent variables) as well as the dependent variable noise annoyance (latent variable). Indicator error terms were allowed to correlate due to potential effects of common method variance. The proposed model is based on the following hypotheses: (i) variations in noise annoyance depend on variations in A-weighted SPLs from the wind turbine so that an increased sound level leads to an increased noise annoyance (path 1 (p1)), (ii) variations in noise annoyance also depend on the individual's attitude towards the noise source, comprising two aspects, namely visual attitude (p2) and general attitude (p3), (iii) there is a moderating effect of visibility, i.e. the effect of noise and general and visual attitude on noise annoyance is different for individuals who can see at least one wind turbine from their dwelling than for those who cannot, (iv) there is a moderating effect of type of terrain, i.e. the effect of noise and general and visual attitude on noise annoyance is different for individuals who live in flat terrain than for those who live in hilly/rocky terrain, (v) there is a moderating effect of area characteristics, i.e. the effect of noise and general and visual attitude on noise annoyance is different for individuals who live in built-up areas than for those living in rural areas, and (vi) there are no moderating effects of gender or age.

Fig. 1. Example of a flat terrain from one of the study areas.

Fig. 2. Example of a hilly/rocky terrain from one of the study areas.

## 3. Method

### 3.1. Design and procedure

The present study is based on data from two field studies on response to wind turbine noise that were carried out in 2000 (Study A) and 2005 (Study B) (Pedersen & Persson Waye, 2004, 2007). The study population consisted of people living in the vicinity of wind turbines in 12 geographical areas in southern Sweden that differed with regard to terrain (flat or hilly/rocky) and degree of urbanization (built-up or rural). One person over the age of 18 in each household situated within approximately 30 dB (A) calculated noise level of the wind turbines was randomly selected. In densely populated areas the sample was randomly further reduced to avoid unnecessary costs. A sample of 1822 people in total were selected and sent a questionnaire masked to give the impression of investigating general living conditions in the countryside. A-weighted SPL from wind turbines outside the dwelling of each subject as well as VVA was calculated and compared with the self-reported response.

### 3.2. Respondents

The questionnaire was completed by 1105 respondents. For the purpose of this paper, 10 questionnaires with missing values for the main response question common to both studies were excluded, leaving 1095 respondents (response rate: 60%). The average age of the respondents was 49.7 (standard deviation (SD) = 14.8) years and 59% were women. The respondents lived in areas with different characteristics. Based on these characteristics the

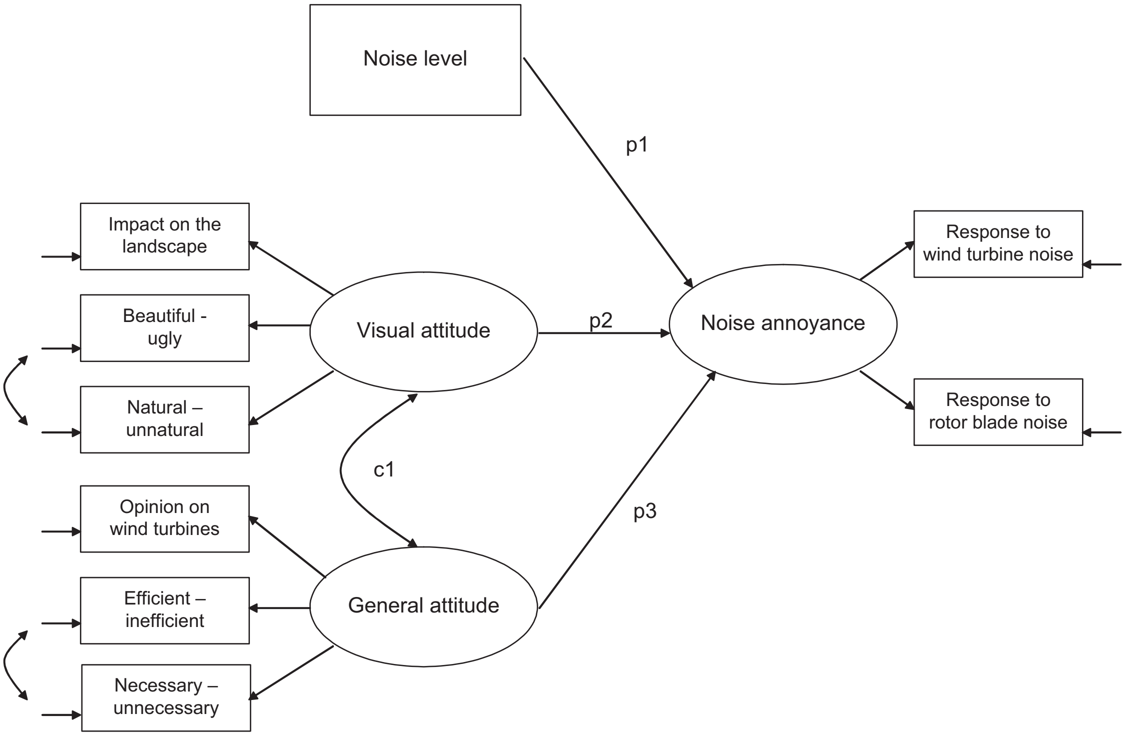

Fig. 3. The structural equation model tested in the present study. "Noise level" refers to calculated A-weighted SPLs outside the dwellings of the respondents due to wind turbine noise. Visual attitude, general attitude and noise annoyance are latent constructs. Regression weights (paths) are labelled "path 1 (p1)" to "path 3 (p3)" and the correlation between visual and general attitude is labelled "c1".

respondents were divided into three pairs of samples used for the SEM and the VVA tests. Of the respondents, 77% ($n=843$) reported that they could see at least one wind turbine from their dwelling, compared with 22% ($n=237$) who could not see a wind turbine from their dwelling (missing values: $n=15$); 66% ($n=720$) lived in flat terrain compared with 34% ($n=375$) who lived in hilly/rocky terrain; and 70% ($n=764$) of the respondents lived in areas classified as built-up compared with 30% ($n=331$) who lived in strictly rural areas. General results were derived from the total sample ($n=1095$).

## 3.3. Measurements

### 3.3.1. Noise annoyance

The main question of response to environmental stressors was phrased, "Specify, for each of the disturbances below, whether you notice it or are annoyed by it outside your dwelling". This was followed by several suggested environmental factors, of which wind turbine noise was the one used in this study, i.e., "Response to wind turbine noise". The subjects were asked to respond on a five-point verbal rating scale (VRS), where 1 = "do not notice", 2 = "notice but not annoyed", 3 = "slightly annoyed", 4 = "moderately annoyed", and 5 = "very annoyed". The same scale was used for perception of noise specified as coming from the rotor blades, i.e., "Response to rotor blade noise". The two measurements of response were used as indicators for *Noise annoyance* (Fig. 3).

### 3.3.2. Visual attitude and general attitude

Two measurements of attitude towards the noise source were included in the study: "opinion on wind turbines" in general and opinion about the wind turbines' "impact on the landscape" scenery. Both were assessed on a five-point VRS ranging from 1 = "very positive" to 5 = "very negative". The subjects were also asked to agree or disagree with 14 descriptive words for wind turbines. Four of these were related to general attitude, namely "necessary", "unnecessary", "efficient" and "inefficient", while four were related to aesthetical aspects, namely "beautiful", "ugly", "natural" and "unnatural". From these eight descriptions of wind turbines, four new variables were constructed. The descriptors of opposite adjectives were put together in pairs so that a new, three-point scale was formed. For example, the new variable "beautiful–ugly" was constructed from "beautiful" and "ugly". If "beautiful" had been chosen by the respondent, this was recorded as 1 on the three-point scale. If "ugly" had been chosen, this was recorded as 3 on the three-point scale, and if neither one had been chosen this was recorded as 2. The new variables were reasonably normally distributed; neither skewness nor kurtosis exceeded the absolute value of 1.0.

The variable measuring "impact on the landscape" and the two constructed variables "beautiful–ugly" and "natural–unnatural" were used as indicators of *Visual attitude* (Fig. 3). The variable "opinion on wind turbines" and the two constructed variables "necessary–unnecessary" and "efficient–inefficient" were used as indicators of *General attitude*.

### *3.3.3. Auditory and visual exposure*

A-weighted SPLs for noise from wind turbines, "Noise level", had previously been calculated for outside the dwelling of each respondent according to the Swedish standards for sound propagation from wind turbines (Swedish Environmental Protection Agency, 2001). Since only data in 2.5 dB(A) intervals were available from Study A, SPLs for these respondents were re-calculated to form a continuous variable before joining data from Study A and Study B into the same database.

To obtain an objective measurement of the wind turbines' visual impact upon people living nearby, the VVA was calculated for each respondent. In this study, VVA was the angle between a horizontal line and an imaginary line from the dwelling of each respondent to the hub of the nearest wind turbine. The calculation therefore takes into account both the closeness and the height of the wind turbine, including the differences in altitude between the base of the wind turbine and the dwelling of the respondent.

### *3.4. Statistical analysis*

Associations between variables were assessed using Pearson's product-moment correlation and linear regression. Differences in means between groups were assessed using Student's *t*-test. All hypothesis tests were two-sided.

SEM, in which the measurements, using confirmatory factor analysis (CFA), and the structural aspects of the model are tested simultaneously, was performed using AMOS, version 4.0 (Arbuckle & Wothke, 1995). Means and SD for variables in the proposed model are presented in Table 1 for each sample tested.

A number of fit indices were considered in testing the fit of the proposed model to the empirical data: the $\chi^2$, the normed $\chi^2$, the root mean square error of approximation (RMSEA) and the comparative fit index (CFI). The $\chi^2$ statistic is a goodness-of-fit measure that assesses the magnitude of the discrepancy between the sample covariance matrix and the estimated covariance matrix (Hu & Bentler, 1995) with a large, statistically significant value relative to the degrees of freedom indicating poor model fit. The normed $\chi^2$ is the ratio of $\chi^2$ to its degrees of freedom. There is no consensus on what precisely represents a good fit (Bollen, 1989), but values larger than 2.0 or than the more liberal limit of 5.0 indicate that the model does not fit the observed data and needs improvement. The RMSEA is a measure of the discrepancy per degree of freedom for the model (Browne & Cudeck, 1993), with values of about 0.05 or less indicating close fit of the model to the data. The CFI is an incremental fit index (Kline, 1998), with values greater than 0.90 indicating acceptable model fit.

There was a low percentage of internal missing values for the variables included in the structural model, ranging from 0% to 1.9% for the individual items. Missing values in the SEM were handled using the full information maximum likelihood (FIML) estimator (see, e.g., Allison, 2003). For other statistical tests, missing values were pairwise excluded.

## 4. Results

### *4.1. General results*

Response to wind turbine noise was positively correlated with A-weighted SPL ($r = 0.37$; $n = 1095$; $p < 0.001$). An increase of 1 dB(A) corresponded to a theoretical increase of 0.12 on the five-point scale ($b = 0.12$; 95% confidence interval (CI) 0.10–0.14; $r^2 = 0.13$). Response to wind turbine noise was also correlated with evaluation of wind turbines in general ($r = 0.3$; $p < 0.001$) and with evaluation of the wind turbines' impact on the landscape ($r = 0.63$: $p < 0.001$). Response to wind turbine noise was related neither to age ($r = -0.02$; $p = 0.575$) nor to sex ($t = 1.04$; df = 1081; $p = 0.300$).

Table 1
Mean and standard deviation (SD) of measured variables in each sample

| | Wind turbines visible | | | | Terrain | | | | Area characteristics | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Yes ($n = 843$) | | No ($n = 237$) | | Flat ($n = 720$) | | Hilly/rocky ($n = 375$) | | Built-up ($n = 764$) | | Rural ($n = 331$) | |
| | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD |
| Noise levels (A-weighted SPL) | 34.2 | 3.16 | 32.1 | 2.27 | 34.5 | 3.12 | 32.4 | 2.60 | 33.7 | 2.83 | 34.0 | 3.68 |
| Response to wind turbine noise | 1.9 | 1.09 | 1.3 | 0.59 | 1.9 | 1.10 | 1.5 | 0.82 | 1.6 | 0.90 | 2.1 | 1.23 |
| Response to rotor blade noise | 1.9 | 1.09 | 1.2 | 0.53 | 1.9 | 1.09 | 1.5 | 0.84 | 1.6 | 0.91 | 2.0 | 1.24 |
| Impact on the landscape | 3.0 | 1.05 | 2.9 | 0.84 | 3.0 | 1.08 | 2.9 | 0.87 | 2.9 | 0.94 | 3.0 | 1.16 |
| "Beautiful–ugly" | 2.2 | 0.64 | 2.2 | 0.61 | 2.2 | 0.65 | 2.2 | 0.60 | 2.2 | 0.61 | 2.2 | 0.68 |
| "Natural–unnatural" | 2.0 | 0.67 | 1.9 | 0.64 | 2.0 | 0.68 | 2.0 | 0.63 | 2.0 | 0.65 | 2.0 | 0.68 |
| Evaluation of wind turbines | 2.3 | 1.00 | 2.2 | 0.95 | 2.3 | 1.00 | 2.2 | 0.97 | 2.2 | 0.95 | 2.3 | 1.06 |
| "Efficient–inefficient" | 1.8 | 0.65 | 1.7 | 0.57 | 1.8 | 0.65 | 1.8 | 0.59 | 1.8 | 0.62 | 1.8 | 0.65 |
| "Necessary–unnecessary" | 1.6 | 0.61 | 1.6 | 0.57 | 1.6 | 0.62 | 1.6 | 0.58 | 1.6 | 0.60 | 1.7 | 0.61 |
| Vertical visual angle | 4.1 | 1.84 | 3.2 | 1.29 | 4.1 | 1.49 | 3.5 | 2.17 | 3.7 | 1.17 | 4.4 | 2.64 |

### 4.2. Model testing

The proposed model was tested separately for those who were (i) visually exposed to wind turbines at their dwellings and those who were not, for those who lived in (ii) flat terrain and those who lived in hilly/rocky terrain, as well as for respondents who lived in (iii) built-up areas and those who lived in rural areas. Exposure levels and response differed slightly between the groups (Table 1). Respondents living in a flat area were exposed to higher levels of wind turbine noise ($t = 10.88$; $p<0.001$) and of VVA ($t = 5.15$; $p<0.001$), and also responded more negatively to the noise, both from wind turbines in general ($t = 6.88$; $p<0.001$) and from the rotor blades ($t = 6.67$; $p<0.001$), than did respondents living in hilly/rocky terrain. Respondents who could see at least one wind turbine from their dwelling, compared with those who could not, were exposed to higher levels of wind turbine noise ($t = 9.39$; $p<0.001$) and larger vertical angles ($t = 6.68$; $p<0.001$), and responded more negatively to the noise from wind turbines ($t = 8.16$; $p<0.001$) and to the noise from the rotor blades ($t = 8.84$; $p<0.001$). Respondents who lived in rural areas, compared with those who lived in built-up areas, responded more negatively to the noise from wind turbines ($t = 6.16$; $p<0.001$) and from rotor blades ($t = 5.61$; $p<0.001$), and were also exposed to larger VVAs ($t = 5.56$; $p<0.001$). No statistically significant differences between the groups were found for the other variables.

Table 2
Relationships between samples; number of respondents

| | Wind turbines visible ($n = 843$) | Wind turbines not visible ($n = 237$) | Flat terrain | Hilly/rocky terrain |
|---|---|---|---|---|
| Flat terrain ($n = 720$) | 619 | 100 | | |
| Hilly/rocky terrain ($n = 375$) | 231 | 138 | | |
| Built-up area ($n = 764$) | 551 | 205 | 421 | 347 |
| Rural area ($n = 331$) | 299 | 33 | 309 | 28 |

The number of respondents in each sample and the distribution of respondents with regard to group classification is shown in Table 2. Respondents that had no wind turbine visible from their dwelling more commonly lived in built-up areas than in rural areas. A large proportion of respondents who lived in flat terrain could see at least one wind turbine from their dwelling. Respondents living in hilly/rocky terrain more commonly lived in built-up areas than in rural areas. Among respondents living in rural areas, 90% could see wind turbines and 93% lived in flat terrain.

The composite reliability (Fornell & Larcker, 1981), measuring the internal consistency for the three constructs noise annoyance, visual attitude and general attitude, was >0.70 in all groups, except for noise annoyance (0.68) and general attitude (0.62) among those with no wind turbines visible, for general attitude among those living in hilly/rocky terrain (0.68) and among those living in built-up areas (0.69). The proposed model showed acceptable fit to the data for all groups of respondents tested (see Figs. 4–6 for fit indices for the respective groups).

#### 4.2.1. Respondents who could see wind turbines from their dwelling vs. respondents who could not

Noise levels had an effect on noise annoyance in the model for both groups, but the effect was significantly

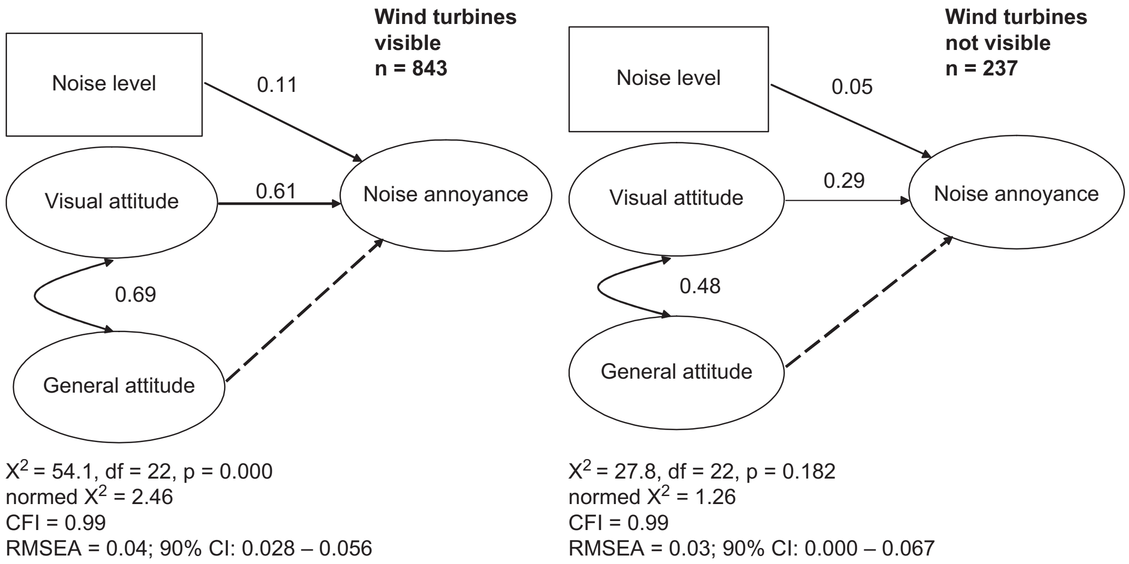

Fig. 4. Structural equation model comparing respondents who could see at least one wind turbine from their dwelling with respondents who could not see any wind turbines from their dwelling. Statistically significant paths (unstandardized estimates) and correlations are annotated with ($p<0.01$). Non-significant paths are marked with dashed lines, and are not annotated.

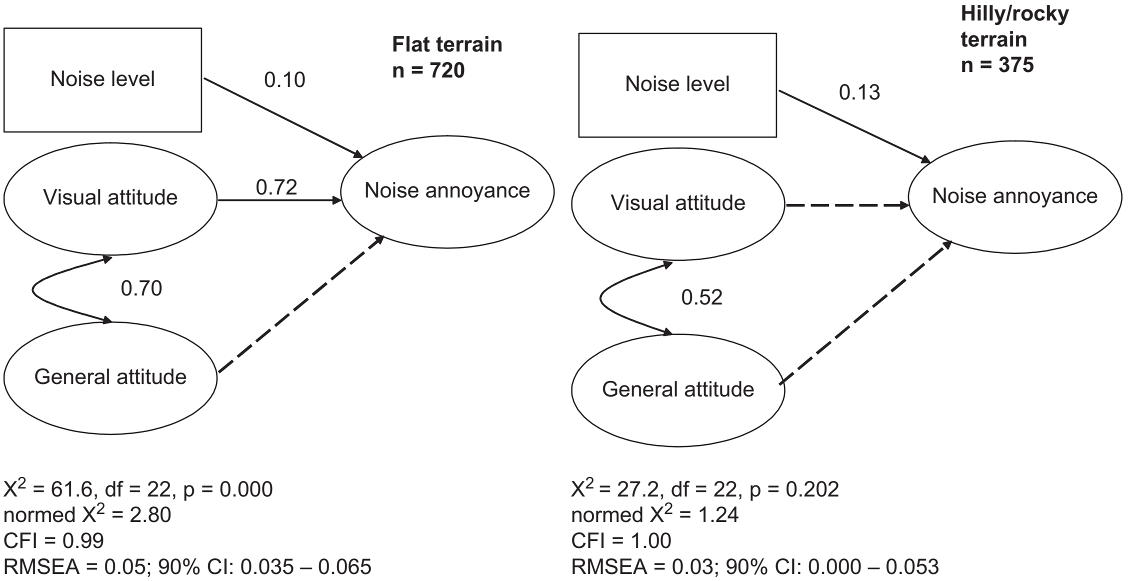

Fig. 5. Structural equation model comparing respondents living in flat terrain with those living in hilly/rocky terrain. Statistically significant paths (unstandardized estimates) and correlations are annotated with ($p<0.01$). Non-significant paths are marked with dashed lines, and are not annotated.

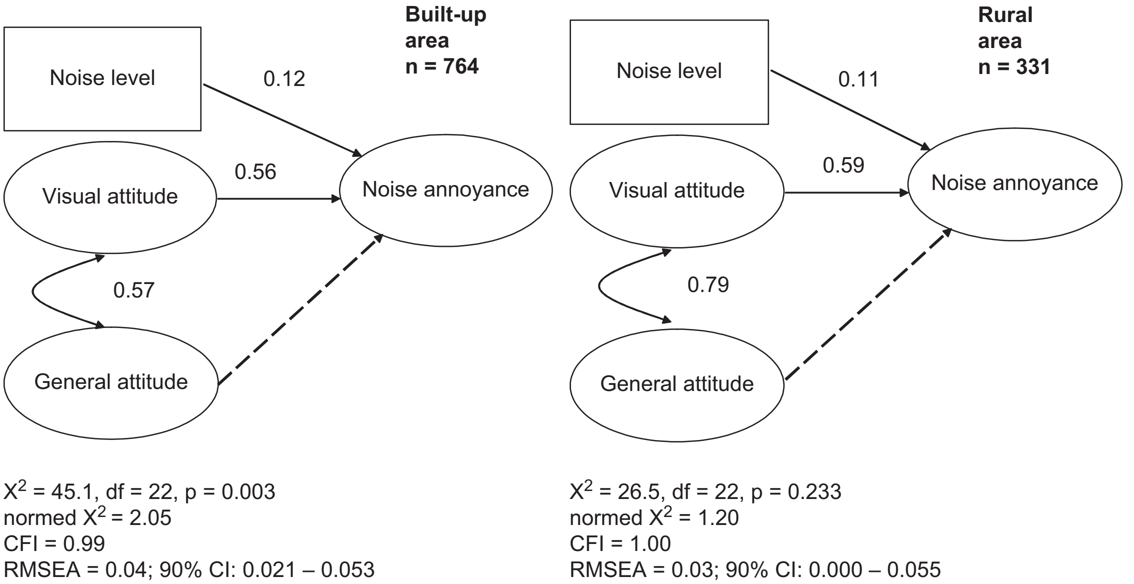

Fig. 6. Structural equation model comparing respondents living in built-up areas with those living in rural areas. Statistically significant paths (unstandardized estimates) and correlations are annotated with ($p<0.01$). Non-significant paths are marked with dashed lines, and are not annotated.

higher for respondents who could see wind turbines than for those who could not (Fig. 4; Table 3). Noise annoyance was also positively influenced by visual attitude, both among respondents who could see the wind turbines and, although to a lower degree, among respondents with no visibility of the turbines. Noise annoyance was not influenced by the general attitude in either group (with visual attitude in the model). Visual attitude and general attitude were positively correlated for both groups. The variance in noise annoyance was in the model explained to 41% among respondents with visibility of wind turbines and to 20% among respondents with no visibility of wind turbines.

### 4.2.2. *Respondents living in flat terrain vs. respondents living in hilly/rocky terrain*

Noise levels had an effect on noise annoyance both for respondents living in flat terrain and for respondents living in hilly/rocky terrain (Fig. 5; Table 4). Noise annoyance was also positively influenced by the visual attitude among respondents living in flat terrain, but not among those living in hilly/rocky terrain. General attitude did not

Table 3
Selected parameter estimates for respondents who could see at least one wind turbine from their dwelling ($n = 843$) and respondents with no visibility of turbines ($n = 237$)

| | At least one wind turbine visible | | | | No wind turbines visible | | | | Differences between estimates* | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Estimate unstd. | Estimate std. | Std. error | *p*-Value | Estimate unstd. | Estimate std. | Std. error | *p*-Value | Diff. | *p*-Value** |
| *Regression weights* | | | | | | | | | | |
| p1: Noise level → noise annoyance | 0.11 | 0.35 | 0.01 | <0.001 | 0.05 | 0.29 | 0.02 | <0.01 | 0.06 | <0.001 |
| p2: Visual attitude → noise annoyance | 0.61 | 0.59 | 0.08 | <0.001 | 0.29 | 0.57 | 0.14 | <0.05 | 0.32 | <0.05 |
| p3: General attitude → noise annoyance | −0.07 | −0.06 | 0.08 | 0.375 | −0.15 | −0.35 | 0.11 | 0.169 | | |
| *Correlations* | | | | | | | | | | |
| c1: Visual attitude and general attitude | 0.69 | 0.78 | 0.04 | <0.001 | 0.48 | 0.83 | 0.06 | <0.001 | 0.21 | <0.01 |

*Difference between unstandardized estimates. Only calculated if the estimates were statistically significant.

**Derived from $Z = (Estimate1 - Estimate2)\Big/\sqrt{SE1^2 + SE2^2}$.

Table 4
Selected parameter estimates for respondents who lived in flat terrain ($n = 720$) and respondents who lived in hilly/rocky terrain ($n = 375$)

| | Flat terrain | | | | Hilly/rocky terrain | | | | Differences between estimates* | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Estimate unstd. | Estimate std. | Std error | *p*-Value | Estimate unstd. | Estimate std. | Std. error | *p*-Value | Diff. | *p*-Value** |
| *Regression weights* | | | | | | | | | | |
| p1: Noise level → noise annoyance | 0.10 | 0.32 | 0.01 | <0.001 | 0.13 | 0.29 | 0.01 | <0.001 | −0.02 | 0.201 |
| p2: Visual attitude → noise annoyance | 0.72 | 0.71 | 0.08 | <0.001 | 0.09 | 0.57 | 0.11 | 0.445 | | |
| p3: General attitude → noise annoyance | −0.19 | −0.16 | 0.08 | 0.058 | 0.13 | −0.35 | 0.10 | 0.191 | | |
| *Correlations* | | | | | | | | | | |
| c1: Visual attitude and general attitude | 0.70 | 0.81 | 0.05 | <0.001 | 0.52 | 0.83 | 0.05 | <0.001 | 0.18 | <0.05 |

*Difference between unstandardized estimates. Only calculated if the estimates were statistically significant.

**Derived from $Z = (Estimate1 - Estimate2)\Big/\sqrt{SE1^2 + SE2^2}$.

influence noise annoyance in either group. Visual attitude and general attitude were positively correlated for both groups. The variance in noise annoyance was in the model explained to 45% for respondents living in flat terrain and to 28% for those living in hilly/rocky terrain.

#### 4.2.3. Respondents living in built-up areas vs. respondents living in rural areas

No main differences between respondents living in built-up areas and respondents living in rural areas were found for the model (Fig. 6, Table 5). Noise annoyance was in both groups positively influenced by noise levels and visual attitude, but not by general attitude. The regression weights were of the same magnitude in both groups. The variance in noise annoyance was for respondents living in built-up areas explained to 39% and for respondents living in rural areas to 42%.

#### 4.2.4. Additional tests

A model with only one attitudinal factor, constructed out of the six measured variables that constructed the two attitudinal factors in the proposed model, was tried for each of the six groups of respondents presented above. The model with only one attitudinal factor did not fit the data as well as the proposed model with two attitudinal factors for any of the six groups (data not shown). The model was also tested with respondents assigned with calculated A-weighted SPLs below the median (<33.4 dB) in comparison with respondents with calculated A-weighted SPLs above the median. Factor loadings were approximately the same for the two exposure groups (data not shown).

### 4.3. Vertical visual angle

The VVA ranged from 1.3° to 19.0°, with a mean value of 3.93 (SD 1.80) among all respondents. The VVA was statistically significantly correlated with A-weighted SPL ($r = 0.70$; $p < 0.001$), which was expected since both VVA and A-weighted SPLs were derived from the distance between the respondent's dwelling and the wind turbine. The VVA was also correlated with response to wind

Table 5
Selected parameter estimates in respondents who lived in built-up areas ($n = 764$) and respondents who lived in rural areas ($n = 331$)

| | Built-up area | | | | Rural area | | | | Differences between estimates* | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Estimate unstd. | Estimate std. | Std error | *p*-Value | Estimate unstd. | Estimate std. | Std. error | *p*-Value | Diff. | *p*-Value** |
| *Regression weights* | | | | | | | | | | |
| p1: Noise level → noise annoyance | 0.12 | 0.42 | 0.01 | $<0.001$ | 0.11 | 0.35 | 0.01 | $<0.001$ | 0.01 | 0.418 |
| p2: Visual attitude → noise annoyance | 0.56 | 0.58 | 0.09 | $<0.001$ | 0.59 | 0.57 | 0.13 | $<0.001$ | −0.03 | 0.873 |
| p3: General attitude → noise annoyance | −0.14 | −0.15 | 0.08 | 0.076 | −0.03 | −0.02 | 0.16 | 0.867 | | |
| *Correlations* | | | | | | | | | | |
| c1: Visual attitude and general attitude | 0.57 | 0.80 | 0.04 | $<0.001$ | 0.79 | 0.81 | 0.08 | $<0.001$ | −0.22 | $<0.05$ |

*Difference between unstandardized estimates. Only calculated if the estimates were statistically significant.

**Derived from $Z = (Estimate1 - Estimate2)\Big/\sqrt{SE1^2 + SE2^2}$.

Table 6
Regression coefficients with 95% confidence intervals (CI) from multiple linear regressions with the dependent variable "response to wind turbine noise"

| | A-weighted sound pressure level | | Revised vertical visual angle | | $R^2$ |
|---|---|---|---|---|---|
| | *B* | 95% CI | *B* | 95% CI | |
| Wind turbines visible | 0.12 | 0.099 to 0.143 | 0.01 | 0.009 to 0.020 | 0.04 |
| Wind turbines not visible | 0.06 | 0.001 to 0.025 | 0.00 | −0.002 to 0.008 | 0.14 |
| Flat terrain | 0.13 | 0.102 to 0.152 | 0.03 | 0.023 to 0.040 | 0.15 |
| Hilly/rocky terrain | 0.13 | 0.104 to 0.161 | 0.00 | −0.001 to 0.008 | 0.20 |
| Built-up area | 0.13 | 0.103 to 0.150 | 0.00 | −0.007 to 0.013 | 0.14 |
| Rural area | 0.11 | 0.078 to 0.145 | 0.01 | 0.003 to 0.016 | 0.14 |

The two independent variables "A-weighted sound pressure level" and "revised vertical visual angle" were entered into the regression simultaneous.

turbine noise ($r = 0.36$; $p < 0.001$). An increase of 1° in VVA corresponded to a 0.2 increase on the five-point scale ($b = 0.21$; 95% CI 0.18–0.24; $r^2 = 0.12$). The influence of VVA on response to wind turbine noise could be an effect of the correlation between VVA and A-weighted SPL. Therefore the common measurement of VVA and A-weighted SPL, i.e. the distance between the respondent and the wind turbine, was removed from the VVA and the variable tested together with A-weighted SPL in a multiple regression, with response to wind turbine noise as dependent variable. The A-weighted SPLs were associated with response to wind turbine noise to the same degree as found previously ($b = 0.13$; 95% CI 0.11–0.15). The new variable derived from the VVA was also associated with response to wind turbine noise, but with a smaller regression coefficient ($b = 0.01$; 95% CI 0.01–0.02). The two variables explained 15% of the variance in response to wind turbine noise. The linear regression was also repeated within the compared groups of interest for this study (Table 6). The revised VVA had an impact on response to wind turbine noise among respondent who could see at least one wind turbine from their dwelling, among respondents living in flat terrain and among respondents living in rural areas.

## 5. Discussion

In the proposed model, visual attitude had a large effect on noise annoyance for four of the six groups while general attitude did not. The model had a better fit in all groups than a model with only one attitudinal variable. These findings indicate that attitude towards a noise source, well known to influence the response to noise, comprises a visual constituent in some situations.

Visual attitude was associated with noise annoyance among respondents living in a flat landscape but not among respondents living in hilly/rocky terrain, even though the visual evaluation of the wind turbines had approximately the same distribution in the two groups. It is well known that disparities in lines and shapes in the environment draw attention as the human visual processing system is specialized to detect contrasts (Kastner & Ungerleider, 2000). Wind turbines in a flat landscape, their towers like exclamation marks against the horizontal lines of the landscape, are likely to draw visual attention, in addition to auditory attention, while in a more differentiated landscape, wind turbines are less prominent. Humans are equipped with multiple sensory channels through which we experience the environment (Stein & Meredith, 1993), and by using our cross-modal capabilities we greatly enhance the ability to recognize and detect external stimuli (Calvert, 2001). The probability of perception of and/or annoyance with wind turbine noise would therefore be large in a landscape in which wind turbines are easily visibly distinguished. However, even for respondents with no visibility of wind turbines from their dwellings, who could therefore not be affected by such a multisensory exposure, visual attitude had a strong impact on noise annoyance. These respondents saw the wind turbines when walking and travelling outside, for instance when commuting to work. These respondents would, however, probably not be simultaneously visually and audibly exposed to the turbines. A plausible explanation for the findings therefore puts forward the notion that aesthetic response (Ulrich, 1983), rather than a multi-sensory effect, is one of the main factors influencing response to wind turbine noise. Wind turbines in a flat landscape are not just easily detected, but could also be appraised as incongruent with the environment. In this way their appraisal in a hilly/rocky landscape, which contains other non-horizontal lines, will be different. In the present study, visual attitude of respondents living in hilly/rocky terrain compared with respondents in a flat terrain was less important for noise annoyance. Certain human-made elements, such as utility poles, have elsewhere been suggested to have a more negative influence on aesthetic evaluation than other types of built features (Brush & Palmer, 1979) supporting this hypothesis. Aesthetic evaluation of the environment has in several studies been shown to be associated with possibilities of psychophysiological restoration (Hartig, Evans, Jamner, Davis, & Gärling, 2003; Hartig & Staats, 2006; Staats, Kieviet, & Hartig, 2003). Consequently, the observed influence of visual attitude on response to wind turbine noise could indicate a hindrance to such restoration, expected or experienced.

Visual attitude towards the noise source, in this case a technical device, did not have a larger impact on noise annoyance among respondents living in a rural area compared to those living in a built-up area. The fact that most respondents in the rural areas both had wind turbines visible and lived in flat terrain, two situations that increased the impact of visual attitude, indicate that living in a built-up area could increase the impact of aesthetical evaluation. This somewhat puzzling finding point to a visual over-load in built-up areas so that people living in environments already comprising man-made objects could be more sensitive to further visual exploitation than others. However, in his study the likeliness between people living in areas with different degrees of urbanization could be due to the built-up areas not being urban, but rather pastoral villages in the countryside or at the edge of a city. Residents in these areas had possibly chosen the environment for qualities such as quietness and beautiful scenery, and would not appraise wind turbines as congruent with their expectations of the living environment. Individuals living in a more rural landscape could have the same expectations, but also a positive view of new economical benefits for the area (Pedersen et al., 2007). The impact of different expectations of the living environment on noise annoyance should be studied further.

The proposed model explained 41% of the variance in response among respondents who could see at least one wind turbine from their dwelling and 45% of the variance in response from respondents living in flat terrain. The degree of explanation was lower in the compared groups, indicating that other factors of impact not taken into account in the proposed model were of importance for respondents who could see no wind turbines from their dwelling and for respondents living in hilly/rocky terrain. The impact of A-weighted SPL was fairly consistent across the groups, with unstandardized regression weights of 0.10–0.13 except for respondents who did not see any wind turbines, for whom the impact of A-weighted SPL was only 0.05. This could be due to somewhat lower noise exposure with less variance in the latter group (Table 1). However, no differences were found when comparing respondents exposed to low noise levels with respondents exposed to high levels of noise. A more plausible explanation is therefore that the observed divergence between regression weights for respondents who could see wind turbines and those who could not was due to physical circumstances. A barrier shielding the view of wind turbines for the respondent also prevents noise propagation, a shielding effect not included in the calculations of A-weighted SPL. An overall dose-response model of noise and response could be skewed by this bias in exposure estimation, an observation probably also valid for other community noise sources studied.

VVA has been brought forward as a factor that could be a better predictor of noise annoyance than A-weighted SPL. This study shows that the difference in altitude between the dwelling of a respondent and the hub of the wind turbine is a possible additional factor influencing noise annoyance in situations were the wind turbine is visible or could be perceived as intrusive in the landscape. The influence was, however, small and noise immission levels are possibly still the best predictor of noise annoyance, at least if situational factors are concurrently considered.

The proposed model was based on theoretical assumptions about causality and on the assumption that attitude towards the source influences noise annoyance. However, we cannot exclude the possibility that the causality is directed the opposite way so that annoyance causes a negative attitude towards the source. Being annoyed by wind turbine noise in the home environment could initiate a negative attitude towards wind turbines. There may also be a feedback loop between these variables.

The study was furthermore limited by the response rate. Of the study sample, 60% responded to the questionnaire. When comparing age and sex of the respondents with demographical data from the area or with non-respondents we found that age distribution was approximately the same, but that a greater percentage of women than of men completed the questionnaire in the study (Pedersen & Persson Waye, 2004, 2007). However, no differences in response to wind turbine noise between the sexes were found. No analysis of the proportion of men and women who were annoyed by wind turbine noise among non-respondents was carried out; however, the questionnaire was masked to give an impression of a survey concerning general living conditions in the countryside to prevent a higher willingness among noise-annoyed individuals compared with non-annoyed individuals to answer.

To summarize, evaluating wind turbines as ugly, unnatural devices that have a negative impact on the scenery increased the probability of noise annoyance, regardless of A-weighted SPL, among respondents in a landscape where wind turbines could be perceived as contrasting with their surroundings. The enhanced negative response could be linked to aesthetical response, rather than to multi-modal effects of simultaneous auditory and visual stimulation, and a risk of hindrance to psychophysiological restoration could not be excluded. It is therefore of importance to take visual attitude towards the noise source into account when exploring response to environmental noise. Furthermore, the association between noise exposure and response should be assessed as being different in different types of landscapes.

## Acknowledgement

We would like to thank the Swedish Energy Agency for funding the study through grant P.22509-1.

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