ABSTRACT

Objectives: To evaluate the prevalence of perception and annoyance due to wind turbine noise among people living near the turbines, and to study relationships between noise and perception/annoyance, with focus on differences between living environments.
Methods: A cross-sectional study was carried out in seven areas in Sweden across dissimilar terrain and different degrees of urbanization. A postal questionnaire regarding living conditions including response to wind turbine noise was completed by 754 subjects. Outdoor A-weighted sound pressure levels (SPLs) were calculated for each respondent. Perception and annoyance due to wind turbine noise in relation to SPLs was analysed with regard to dissimilarities between the areas.
Results: The odds of perceiving wind turbine noise increased with increasing SPL (odds ratio, OR = 1.3; 95% confidence interval, CI, 1.25–1.40). The odds of being annoyed by wind turbine noise also increased with increasing SPLs (OR=1.1; 95% CI 1.01–1.25). Perception and annoyance was associated with terrain and urbanization, so that (i) a rural area increased the risk of perception and annoyance in comparison with a suburban area; and (ii) in a rural setting, complex ground (hilly or rocky terrain) increased the risk in comparison to flat ground. Annoyance was associated with objective and subjective factors of wind turbine visibility. Annoyance was further associated with lowered sleep quality and negative emotions. This, together with reduced restoration possibilities may adversely affect health.
Conclusion: There is a need to take the unique environment into account when planning a new wind farm so that adverse health effects are avoided. The influence of area-related factors should also be regarded in future community noise research.

Main messages

- The risk for being annoyed by wind turbine noise increases with increasing A-weighted sound pressure levels. Dose-response relationships at noise levels as low as these have not earlier been derived.
- Living in a rural environment, in comparison with a suburban area, increases the risk of perceiving and being annoyed by sound from nearby wind turbines.
- Noise annoyance with wind turbine noise could lead to hindrance of human restoration.
- Seeking information and discussing wind turbines as a coping strategy could decrease adverse health effects.

Policy implications

- To avoid annoyance, the characteristics of a geographical area should be taken into account when establishing new wind farms.
- Dose-response relationships between exposure to community noise and noise annoyance should be assessed not just on a general level, but for different living environments.

INTRODUCTION

Wind power is a relatively new form of electricity generation that has a low impact on the environment compared with other power sources[1] and is also favoured by the public, at least by those not saddled with a wind turbine project in their own local community.[2] One disadvantage is the noise that inevitably emits from the rotor blades. Typically sound power levels of a modern wind turbine range from 98 to 104 dB(A) at a wind speed of 8 m/s, which result in 33–40 dB(A) at a dwelling 500 m away, though this depends on meteorological and ground conditions. Sound pressure levels (SPLs) of this low magnitude are not considered a problem when it comes to other sources of community noise, such as road traffic and aircraft, but two circumstances increase the risk of negative perception of the sound from wind turbines: the sound character and the localization. The sound is amplitude modulated by the pace of the rotor blades, which gives a rhythmical swishing sound. Such sounds are known to be more easily perceived than an even sound[3] and possibly also are more negatively appraised. In a rural environment the turbines are prominent and since the rotor blades move in an otherwise fairly still environment they are likely to draw visual attention.

We do not know the prevalence of perception and possible effects of wind turbine noise at a generalized level as only few studies have been carried out. In an investigation of the impact of wind turbines on people living near wind turbines in a flat landscape, a dose-response relationship between A-weighted SPL and annoyance due to wind turbine noise was found.[4] The relationship was, however, moderated by the respondents' attitude to the visual impact of the turbines on the landscape. In a Danish study, also carried out in a flat landscape, the angle from the subject to the hub of the wind turbine was more correlated to perception of the noise than to SPL.[5] There are therefore reasons to believe that the prevalence of noise annoyance may be influenced by the variation in visibility of the wind turbines between different landscapes, such as a flat landscape and a hilly ground.

In one study, interviews with 15 subjects revealed additional possible associations between landscape and perception of wind turbine noise.[6] The subjects' personal values relating to the living environment appeared to influence how the noise from the wind turbines was perceived. Some, who considered the countryside as a place for economic growth and technical achievements, were indifferent to noise exposure from the wind turbines. Others, who emphasized that the countryside should be a quiet and peaceful place for restoration, felt that the noise intruded their privacy and hence had a negative impact on their quality of life. People in the latter category would presumably seek living environments consistent with their needs, and may therefore be overrepresented in areas they perceive as quiet and peaceful. It could therefore be hypothesized that exposure from wind turbines would be more negatively appraised in an area that is perceived as unspoiled than in an area with several human activities going on.

AIMS

The objectives of this study were to evaluate the prevalence of perception and annoyance due to wind turbine noise among people living in the vicinity of one or more turbines, and to study relationships between noise and perception/annoyance with focus on differences between different living environments.

METHODS

General outline

For this cross-sectional study, we selected seven wind turbine areas in Sweden that represented different types of landscapes with regard to terrain and urbanization. To assess the prevalence of perception of and annoyance with wind turbine noise, a questionnaire was sent to a sample of people living near the wind turbines. The questionnaire was masked to give the impression of investigating general living conditions in the countryside. Outdoor A-weighted SPL was calculated for each respondent to estimate the exposure to wind turbine noise outside their dwelling. Perception of and annoyance with wind turbine noise were analysed in relation to exposure and with regard to possible variables of influence on the relationship.

Study areas and study samples

Areas with different terrain and a population density large enough to meet the criteria of the power calculations were sought among all areas in Sweden containing wind turbines with a nominal power of more than 500 kW (n=478 in 2004). Areas with offshore wind turbines, and turbines placed close to noisy industries and highways were excluded. Of the seven areas selected, three had flat ground (Areas V–VII) and four had complex ground (Areas I–IV), i.e. the ground was rocky and/or the altitude of the base of the wind turbine differed considerably from that of the dwellings nearby. Areas I, IV and VII were classified as suburban; areas II, III, V and VI as rural. Some of the areas also contained wind turbines with a nominal power less than 500 kW. We included two areas with few inhabitants (Areas II and III) as it was difficult to find areas with complex ground and a higher population density.

Addresses with coordinates of people living within a preliminary calculated isobar of 30 dB(A) from a wind turbine were bought from a postal delivery company and a sample of one randomized person in each household was constructed. In areas with a study population of more than 500 (Areas I, IV and VII), the sample was further reduced by randomly excluding half of the households among those living at SPL <35 dB(A) to avoid unnecessary costs. In total, 1,309 questionnaires were sent out (Table 1).

Questionnaires were satisfactorily completed and returned by 754 subjects (57.6%). Respondents were statistically significantly older than non-respondents (mean age 51 v. 47 years; Students' t-test, p<0.001) and an insignificantly greater number of respondents compared with non-respondents were females (55% v. 47%; Mann-Whitney U-test, p=0.131). The distribution of age and sex between the respondents and the non-respondents was approximately the same in all seven areas.

The study was carried out in accordance with the requirements of the national and regional ethics committees in Sweden.

Table 1 Study population, sample, respondents and response rate, and descriptive data of respondents and exposure related to area.

Area	I	II	III	IV	V	VI	VII	Total
Study population	1,085	40	48	672	311	217	1,098	3,471
Sample	396	24	23	221	148	112	385	1,309
Respondents	206	16	12	141	87	70	222	754
Response rate (%)	52.0	66.7	52.2	63.8	58.8	62.5	57.7	57.6
Description of respondents and exposure								
Age (yrs), mean (SD)	52 (15)	51 (18)	54 (15)	52 (14)	49 (16)	49 (15)	51 (15)	51 (15)
Sex (% male)	40	53	58	47	48	38	46	44
Occupation (% employed) (% retired)	54 28	33 53	58 33	57 24	61 22	58 21	62 23	58 25
Housing type (% detached)	70	93	100	70	89	93	82	79
Length of time in current dwelling (yrs), mean (SD)	14 (14)	16 (10)	16 (15)	15 (13)	15 (15)	15 (16)	16 (12)	15 (13)
Distance to nearest wind turbine (m), mean (SD)	862 (184)	636 (254)	670 (284)	812 (151)	834 (266)	1,014 (245)	605 (160)	780 (233)
Sound pressure level (dB(A)), mean (SD)	31.4 (2.3)	38.2 (4.7)	33.8 (4.5)	33.2 (1.4)	34.6 (3.2)	31.9 (2.3)	35.0 (2.9)	33.4 (3.0)
Visual angle (degree), mean (SD)	3.5 (0.9)	10.8 (3.9)	8.4 (4.3)	2.5 (0.4)	2.7 (1.3)	3.5 (1.7)	3.8 (0.8)	3.5 (1.7)
Visibility (% of respondents who could see at least one wind turbine)	64	75	67	60	91	88	71	71
Noise sensitivity (% sensitive)	54	50	42	59	39	56	48	51
Self-rated health (% chronic disease)	36	33	67	35	21	26	32	33
Self-rated sleep (% not good)	9	0	0	6	5	4	5	6

Subjective variables assessed by the questionnaire

The questionnaire consisted of questions on living conditions, reaction to possible sources of annoyance in the living environment, sensitivity to environmental factors, health and wellbeing. The questionnaire has been used and evaluated in a previous study.[4] Perception of and annoyance with wind turbine noise were assessed (together with other environmental stressors) by the question, “Specify for each of the inconveniences below whether you notice it or are annoyed by it outside your dwelling”, with a five-point verbal rating scale (VRS), where 1 = “do not notice”; 2 = “notice but not annoyed”; 3 = “slightly annoyed”; 4 = “rather annoyed”; and 5 = “very annoyed”. Noise sensitivity was assessed with a four-point VRS ranging from 1 = “not sensitive at all”, to 4 = “very sensitive”. The questionnaire also comprised specific questions about wind turbines, related to the respondent by the recent development of wind turbines in the community. Attitudes to wind turbines in general and to their impact on the landscape were assessed with a five-point VRS ranging from 1 = “very positive”, to 5 = “very negative”.

General coping was assessed by 15 items originally developed by Lercher,[7] and in our study translated and slightly modified to Swedish conditions. Questions on coping with wind turbines (eleven items) and the respondents’ descriptions of their living environment (ten items) were derived from a previous study based on 15 in-depth interviews with people living near wind turbines[6] (five-point VRS ranging from 1 = “do not agree at all”, to 5 = “completely agree”). Respondents were also asked about their emotions when thinking about wind turbines, their set of values of their living environment, and their status of health (chronic disease, e.g. diabetes or cardio-vascular disease), wellbeing and sleep.

Noise exposure assessment

For each wind turbine, the sound power levels (dB) in octave bands were obtained from the manufacturers. The standard model of sound propagation proposed by the Swedish Environmental Protection Agency [8] was then used to estimate the noise immission outside each respondent’s dwelling as equivalent continuous A-weighted SPL (dB). The model is based on downwind conditions (±45°) with a wind speed of 8 m/s at 10 m height. The distance between the respondent and the nearest wind turbine was calculated using geographical coordinates. For those respondents in Area I who lived on the far side of a small bay from the wind turbine, 1.5 dB(A) were added to the calculated A-weighted SPL (personal communication with Sten Ljunggren, developer of the used sound propagation algorithm). The same was done for respondents living in Area II where there were large differences in altitude between the wind turbine and the respondents, which is known to enhance sound propagation.[9] In areas with several wind turbines, the A-weighted SPLs received by the respondent were added logarithmically.

Vertical visual angle

To study the influence of a tall object near the dwelling, the vertical visual angle was calculated for each respondent. “Vertical visual angle” in this study was defined as the angle between the horizontal plane and an imaginary line from a respondent’s house to the hub of the nearest wind turbine, expressed in degrees.

Subjective background sound

Using principal component analysis the variable “subjective background sound” was derived from three items in the questionnaire. Respondents were asked to agree or not agree on a five-point VRS to the following statements: (i) “when outside on a calm summer morning, I can hear only bird song and other nature sounds”; (ii) “a background noise from road traffic is almost always present outdoors”; and (iii) “it is never really quiet in the area”. The mean values of the factor scores differed between the areas ($F=4.137$, $p<0.001$). Three quiet areas (Areas IV, VI and VII) and two not quiet (Areas I and V) were identified in a post hoc test (Least Significant Different, LSD). Areas II and III were excluded as they did not significantly differ from areas in either group.

Statistical treatment of data
The relationship between A-weighted SPL and response to wind turbine noise did not fulfil the proportional odds assumption required for ordinal logistic regression. Perception and annoyance were therefore analysed separately using binary logistic regression. The depending variable, i.e. response to wind turbine noise, was dichotomized: perception into "do not notice" and "notice" (1/2–5) and annoyance into "not annoyed" and "annoyed" (1–3/4–5). Factors related to the differences of the areas and possible moderating factors were analysed one by one in the regressions, always keeping A-weighted SPL in the model as the main factor of impact. Though age and sex are not known to have any influence on response to community noise,[10] these factors were included in the analyses to exclude bias from observed differences between areas. Several parameters were hypothesized to have an influence on perception: terrain, degree of urbanization, subjective background noise level, employment (not employed spending more time at home), housing (residents in detached houses spending more time outside) and visibility (i.e. respondents seeing at least one wind turbine from their dwelling, meaning there are no barriers between the noise source and the receiver). Some of these parameters were also hypothesized to influence noise annoyance, in addition to factors of how long the respondents had lived at their current address, noise sensitivity,[11] attitude to the source,[12, 13] and respondents' description of their living environment.[6] Noise sensitivity was dichotomized into "not sensitive" and "sensitive" (1–2/3–4), and attitude into "not negative" and "negative" (1–3/4–5). Odds ratios (ORs) with 95% confidence intervals (CIs) not including 1.0 were considered statistically significant.

Two models predicting noise perception were derived by simultaneously entering variables associated with perception into a binary logistic regression and then excluding no longer significant variables one by one. The models were tested using the Hosmer and Lemshow test (a high p-value indicates a good fit). Modelling with more than two factors was not possible for annoyance, because of the low incidence.

Principle component analysis with Varimax was used for deriving factors from the eleven items assessing coping with wind turbines. Items were excluded if they did not fulfil the following criteria suggested by Hair et al.[14]: extraction communality <0.5, measure of sampling adequacy >0.5, not loading more than 0.2 on two factors. Derived factors with Cronbach's alpha <0.6 for the included items were rejected.

Correlations were tested using Spearman's rank test. Differences in distribution between groups were tested with Mann-Whitney's U-test for variables with ordinal scales, using the chi^2 test for dichotomous variables, and one-way analysis of variance (ANOVA) for continuous variables. The tests were two-sided. P-values <0.05 were considered statistically significant. The 95% CIs for proportions were calculated using the Wilson's method in accordance with Altman.[15]

RESULTS

Descriptive data of respondents and exposure

Table 1 shows the demographic characteristics of respondents in each area and in total. The mean age was approximately the same for all areas, but the proportion of men differed (range 38–58%). Most of the respondents were employed (58%) or retired (25%); Area III had the lowest proportion of employed and the highest proportion of retired respondents, but this area only contributed 14 respondents. “Not employed” comprised unemployed individuals (4% of all respondents), respondents on parental leave (3%), respondents on sick leave (2%) and home workers (1%). Most people lived in single-family detached houses, but Areas I and IV also featured rented or tenant-owned apartments.

The largest mean vertical visual angles were found in Areas II (10.8^{o}) and III (8.4^{o}) where the wind turbines were situated on top of a hill. The highest proportions of respondents who could see at least one wind turbine from their dwelling were found in Areas V (91%) and VI (88%), characterized as rural areas with flat ground. The highest proportions of noise-sensitive respondents were found in Areas IV (59%) and VI (56%), both areas that had been classified as quiet.

Perception

Perception of and annoyance with wind turbine noise were correlated with A-weighted SPL ($p<0.001$). Of all the respondents, 39% (n=307) noticed sound from wind turbines outside their dwelling. The proportion of respondents who noticed sound increased almost linearly with increasing SPL (Figure 1). At 37.5–40.0 dB(A), 76% of the 71 respondents within that category of sound level reported that they noticed sound from the wind turbines while at >40.0 dB(A), 90% of 20 did. Respondents who slept with an open window in the summer or in the winter did not perceive the noise to a higher degree than did other respondents within the same category of sound level, as presented in Figure 1 (p-values in the range of 0.067–1.00; p-values <0.3 were all related to <u>lower</u> perception if sleeping with the window open).

Table 2 shows the association between SPL and perception of noise from wind turbines; the odds of noticing sound increased by 30% for each dB(A) increase. Perception was not associated with sex or age. Being employed, living in a detached house, living in an area with low subjectively rated background noise and seeing at least one wind turbine from the dwelling increased the odds of noticing the sound. Terrain did not statistically significantly influence the perception, but the OR for noticing sound from wind turbines in rural areas compared with suburban areas was 1.8. When further exploring this finding, we found that respondents living in rural areas with complex ground were more likely to notice the sound than others.

Model 1 (Table 2) predicts perception of wind turbine noise. Housing was no longer statistically significant and was therefore excluded. All other variables were still associated with perception; urbanization and subjective background noise to a higher degree than when tested one by one. Living in an area with flat ground now decreased the likeliness of hearing the sound. In Model 2 (Table 2) the more differentiated variable of "terrain and urbanization" was examined. Living in an area with complex ground increased the likeliness of noise perception both in a rural and in a suburban setting.

Table 2 Association between perception of noise from wind turbines (dependent variable "do not notice" (n=457) or "notice" (n=307)) and variables hypothesized to influence the perception, expressed as odds ratio (OR), with 95% confidence intervals (CIs).

Sound pressure level (dB(A))	**Other variables hypothesized to influence perception**	
OR (95% CI)	**Variable of interest (ref; tested category)***	**OR (95% CI)**
1.3 (1.25–1.40)		
	Demographic and socio-economic factors	
1.3 (1.26–1.41)	Age (yrs; + 1 year)	1.0 (0.99–1.01)
1.3 (1.25–1.41)	Sex (male; female)	1.0 (0.83–1.16)
1.3 (1.26–1.41)	Employment (employed; not employed)	0.7 (0.48–0.91)
1.3 (1.26–1.41)	Housing (apartment; detached house)	1.6 (1.04–2.33)
	Area-related factors	
1.3 (1.24–1.40)	Terrain (complex; flat)	1.1 (0.81–1.56)
1.3 (1.25–1.41)	Urbanization (suburban; rural)	1.8 (1.27–2.64)
1.3 (1.24–1.41)	Terrain and urbanization	
	Suburban and flat ground (n=222)	1.0
	Suburban and complex ground (n=347)	1.0 (0.65–1.48)
	Rural and flat ground (n=157)	1.6 (1.01–2.53)
	Rural and complex ground (n=28)	4.8 (1.65–13.72)
1.3 (1.22–1.38)	Subjective background noise (not quiet; quiet)	1.8 (1.25–2.51)
	Visual factors	
1.3 (1.22–1.37)	Visibility (no; yes)	2.2 (1.47–3.18)
Model 1†‡ (Hosmer and Lemshow test: 0.703)		
Sound pressure level (dB(A))		1.3 (1.21–1.39)
Employment (employed; not employed)		0.6 (0.40–0.83)
Terrain (complex; flat)		0.6 (0.38–0.97)
Urbanization (suburban; rural)		2.3 (1.34–3.88)
Subjective background noise (not quiet; quiet)		2.6 (1.72–3.95)
Visibility (no; yes)		2.3 (1.51–3.47)
Model 2†‡ (Hosmer and Lemshow test: 0.703)		
Sound pressure level (dB(A))		1.3 (1.21–1.39)
Employment (employed; not employed)		0.6 (0.40–0.83)
Terrain and urbanization		
Suburban and flat ground (n=222)		1.0
Suburban and complex ground (n=347)		1.6 (1.03–2.63)
Rural and flat ground (n=157)		2.2 (1.34–3.89)
Rural and complex ground (n=28)		13.8 (4.24–45.14)
Subjective background noise (not quiet; quiet)		2.6 (1.72–3.95)
Visibility (no; yes)		2.3 (1.51–3.47)

*Variables were entered one by one into a binary logistic regression, always keeping SPL in the regression as the main factor of importance for perception.
†Model 1 and 2 comprise several variables simultaneously entered into a binary logistic regression.
‡Adjusted for age and sex.

Annoyance

The total number of respondents who were annoyed by wind turbine noise in this study was 31. The proportion of respondents who were annoyed at low SPL varied from 3% to 4%, but at 37.5–40 dB(A) the proportion increased slightly to 6% of the 71 respondents within that category of sound level, and at SPL >40 dB(A) it further increased to 15% of 20 respondents, as shown in Figure 2. The increase was not statistically significant, largely because of the low numbers of respondents living at SPL >40 dB(A).

Table 3 Association between annoyance with noise from wind turbines (dependent variable "not annoyed" (n=723) or "annoyed" (n=31)) and variables hypothesized to influence annoyance, expressed as odds ratio (OR), with 95% confidence intervals (CIs).

Sound pressure level (dB(A))	**Other variables hypothesized to influence perception**	
OR (95% CI)	**Variable of interest (ref; tested category)***	**OR (95% CI)**
1.1 (1.01–1.25)		
Demographic and socio-economic factors		
1.1 (1.03–1.27)	Age (yrs; + 1 year)	1.0 (0.99–1.04)
1.1 (1.02–1.26)	Sex (male; female)	0.9 (0.50–1.64)
1.1 (1.01–1.25)	Employment (employed; not employed)	1.3 (0.61–2.60)
1.1 (1.01–1.25)	Housing (apartment; detached house)	2.5 (0.75–8.40)
1.1 (1.01–1.25)	Length of time in current dwelling (yrs, + 1 year)	1.0 (1.00–1.05)
Area-related factors		
1.1 (1.02–1.26)	Terrain (complex; flat)	0.8 (0.39–1.76)
1.1 (0.99–1.21)	Urbanization (suburban; rural)	3.8 (1.80–7.83)
1.1 (0.98–1.23)	Terrain and urbanization Suburban and flat ground (n=222) Suburban and complex ground (n=347) Rural and flat ground (n=157) Rural and complex ground (n=28)	 1.0 2.1 (0.63–7.28) 5.2 (1.62–16.65) 10.1 (2.46–41.61)
1.1 (0.91–1.21)	Subjective background noise (not quiet; quiet)	3.6 (1.21–10.67)
Noise sensitivity and attitude to source		
1.1 (1.02–1.26)	Noise sensitivity (not sensitive; sensitive)	2.5 (1.14–5.63)
1.1 (1.00–1.25)	Attitude to wind turbines in general (not negative; negative)	13.4 (6.03–29.59)
1.1 (1.01–1.25)	Attitude to the visual impact of the wind turbine on the landscape (not negative; negative)	14.4 (6.37–32.44)
Valuation of the current living environment†		
1.1 (1.01–1.25)	"I live in a place for restoration" (disagree; agree)	0.3 (0.13–0.74)
1.1 (1.02–1.25)	"I have renovated my dwelling" (no; yes)	2.6 (1.03–6.33)
Visual factors		
1.0 (0.88–1.16)	Vertical visual angle (degrees; + 1 degree)	1.2 (1.03–1.42)
1.1 (0.97–1.21)	Visibility (no; yes)	10.9 (1.46–81.92)

*Variables were entered one by one into a binary logistic regression, always keeping sound pressure level (SPL) in the regression as the main factor of importance for perception.
†Only items that were positively or negatively associated with noise annoyance are shown.

The odds of being annoyed by noise from wind turbines increased significantly with A-weighted SPL (Table 3). Age, sex, employment, type of housing and length of time in current dwelling were not associated with annoyance. Living in a rural area, living in an area with low subjectively rated background noise, being noise-sensitive, and having a negative attitude to wind turbines in general or to their visual impact on the landscape were factors positively associated with annoyance. Of the ten items measuring the respondents' description of the living environment, the following two were associated with annoyance: (i) having renovated the dwelling was positively associated with noise annoyance; while (ii) looking upon the current living environment as a place for restoration was negatively associated with noise annoyance. Having renovated the dwelling was not correlated to coping with wind turbines by changing the living environment, as asked about later in the questionnaire ($p=0.730$). Both the objective variable "vertical visual angle" and the subjective report of visibility of wind turbines increased the odds of being annoyed.

Subjective ratings of health and wellbeing

A-weighted SPL was not correlated to any of the health factors or factors of wellbeing asked for in the questionnaire. However, noise annoyance was associated with sleep quality and negative emotions. Of those 31 respondents who were annoyed by wind turbine noise, 36% reported that their sleep was disturbed by a noise source, compared with 9% among those 733 not noise annoyed ($p<0.001$). Respondents who were annoyed by wind turbine noise felt more tired ($p=0.05$) and tense ($p<0.05$) in the morning. They also felt resigned (29%), violated (23%), strained (19%) and tired (19%) when thinking about wind turbines to a statistically significantly higher degree compared with those who were not annoyed (all p-values <0.001). These feelings were not related to self-reported health status, except for feeling violated, which was associated with bad sleep ($p<0.01$).

Coping

Several of the eleven items measuring coping specific to wind turbine noise were correlated to noise annoyance. Two factors, which explained 72% of the variance in the original variables, were derived, viz. (i) taking active steps to avoid the negative impact ("I have changed my living environment because of the wind turbines"; "I have changed my behaviour because of the wind turbines"; "I consider moving if more wind turbines are erected"); and (ii) discussing and seeking information ("I have gathered information about wind power"; "I discuss wind power with people around me"). Both factors were positively correlated to noise annoyance (for (i), $p<0.001$; for (ii), $p<0.01$). "Taking active steps to avoid the negative impact" was not correlated to any of the questions assessing wellbeing. "Discussing and seeking information" was negatively correlated to three out of five items assessing stress or strain (unhappiness/depression, irritability, feelings of hopelessness; all p-values <0.05), indicating that this group of respondents were less under strain than others. None of the 15 items measuring general coping were correlated to annoyance with wind turbine noise.

DISCUSSION

Living in a rural landscape in contrast to an urbanized area enhanced the risk of perceiving wind turbine noise and, furthermore, the risk of annoyance. Type of terrain had no major influence on perception in urbanized areas; however, in a rural landscape, complex terrain substantively increased the risk. These results suggest, together with the higher risk of perception in areas rated as quiet, that there is a need to take the special features of an environment into account when assessing the risk of nuisance for people living in the area.

The findings of our study could in part be explained by differences in levels of background sound between rural and urbanized areas. However, not just perception but also annoyance was associated with type of landscape, indicating that the wind turbine noise interfered with personal expectations in a less urbanized area. Having renovated the dwelling was another variable that was positively associated with annoyance, pointing towards a personal factor related to the living environment, which affects response to an environmental stressor. Theories used in studies of residential environments have revealed that people choose environments that harmonize with their self-concept and needs, and that they remain in places that provide a sense of continuity.[16] When a new environmental stressor occurs, the individual's relationship with her or his place of residence is disrupted.[17] Such a distortion could possibly predispose for an increased risk of annoyance such as measured in our study.

The increased risk of perception of wind turbine noise in a rural landscape with a complex terrain compared with a flat terrain could be due to shelter effects decreasing the background noise at the respondent's dwelling where the houses are located in a valley and the turbine on a hill. Also, it cannot be excluded that the model used for calculating the sound propagation underestimates the A-weighted SPL at the respondent's dwelling more than compensated for in this study, in cases where there are large differences in altitude between the source and the receiver.[9]

The association between perception of wind turbine noise and A-weighted SPL was statistically significant and consistent (OR=1.3) even when several moderating variables were tested. The association between noise annoyance and sound level (OR=1.1) was also consistent for most moderating variables, even though it was not always statistically significant, largely owing to the low number of annoyed persons. However, when the vertical visual angle was tried in a logistic regression, the association between annoyance and sound decreased (OR=1.0). Both A-weighted SPL and vertical visual angle were calculated from the distance between the respondent and the wind turbine, so the decrease may be due to the dependence of the variables. The decrease could also be seen as an indication of the visual influence that wind turbines have on noise annoyance. Seeing one or more turbines increased not just the odds of perceiving the sound, but also the odds of being annoyed, suggesting a multimodal effect of the audible and visual exposure from the same source leading to an enhancement of the negative appraisal of the noise by the visual stimuli. This effect has previously been observed in a field study where traffic noise was found to be more annoying if the source of the noise (moving road traffic) could be seen.[18] On the other hand, the increased odds of being annoyed, observed among respondents with a negative attitude to the wind turbine's visual impact on the landscape, point to a more aesthetic explanation: respondents who think of wind turbines as ugly are more likely to appraise them as not belonging to the landscape and therefore feel annoyed, also by the noise. Experimental studies have shown that the same noise level of traffic generates a higher degree of noise annoyance when pictures of an urban setting rated as not pleasant are shown as compared with pictures of a more pleasant area. [20]

Annoyance is an adverse heath effect.[21] Community noise has in some studies also been linked to other non-auditory health effects, for example in a recently published study on aircraft noise and hypertension.[22] However, these studies have mainly explored sound levels >50 dB(A) and the results are therefore not relevant for effects of wind turbine noise.[23] In our study no adverse health effects other than annoyance could be directly connected to wind turbine noise. Reported sleep difficulties, as well as feelings of uneasiness, associated with noise annoyance could be an effect of the exposure, but it could just as well be that respondents with sleeping difficulties more easily appraise the noise as annoying. Wind turbine noise as a hindrance to restoration could, however, not be excluded. Being employed was, contrary to the hypothesis, associated with higher prevalence of perceiving wind turbine noise, possibly because individuals who leave the house for work are more observant of stressors that could interfere with their restoration needs when at home. Furthermore, respondents who were annoyed by the noise did not think of their living environment as a place for restoration. The need for restorative environments in order to maintain health and wellbeing, especially for vulnerable groups, has been frequently pointed out, by such authors as Kaplan.[24] The fact that a non-urbanized setting has been linked to restorative properties such as "not being distracted"[25] suggests that audio and visual distractions caused by wind turbines could change a rural environment from restorative to non-restorative.

Of the coping strategies identified, discussing and seeking information appeared to be most successful as this was correlated with less strain. This finding should be acknowledged in the planning of wind turbines, by giving people living in intended wind farm areas relevant information and possibilities to communicate with the developers and authorities.

Our study had some limitations, apart from the difficulties in assessing the exposure mentioned above. Participation was incomplete (response rate 57.6%), but response bias would only explain the influence of urbanization and terrain if people in one type of area perceiving the noise would be more willing to answer the questionnaires than people in another. This seems unlikely, and similar associations were found when examining those who responded to the questionnaire at the first invitation and those who required one or two reminders (data not presented). It can also not be excluded that differences between the areas, other than terrain and degree of urbanization, could have influenced the results, for instance local opinion groups and media discussions. Using seven different areas located in different parts of southern Sweden reduced this risk.

The findings of this study are probably relevant for other sources of community noise, such as road traffic and airports. There has been a tradition of focusing on synthesized dose-response relationships for a specified noise source irrespective of environment, even though the results of the studies often differ.[27] Difficulties to accurately predict noise annoyance of particular communities from modelled dose-response curves has also been reported.[28] A recent study of annoyance with noise in an alpine valley, in which data were separately analysed for neighbouring communities, found differences in dose-response relationship between areas; however, the authors do not explain the reasons for the observed differences.[29]

Future research should not only take into account individual factors already known to moderate the dose-response relationship, such as noise sensitivity and attitude to the source, but should explore the influence of dissimilar environments, in our study associated with perception of and annoyance with wind turbine noise.

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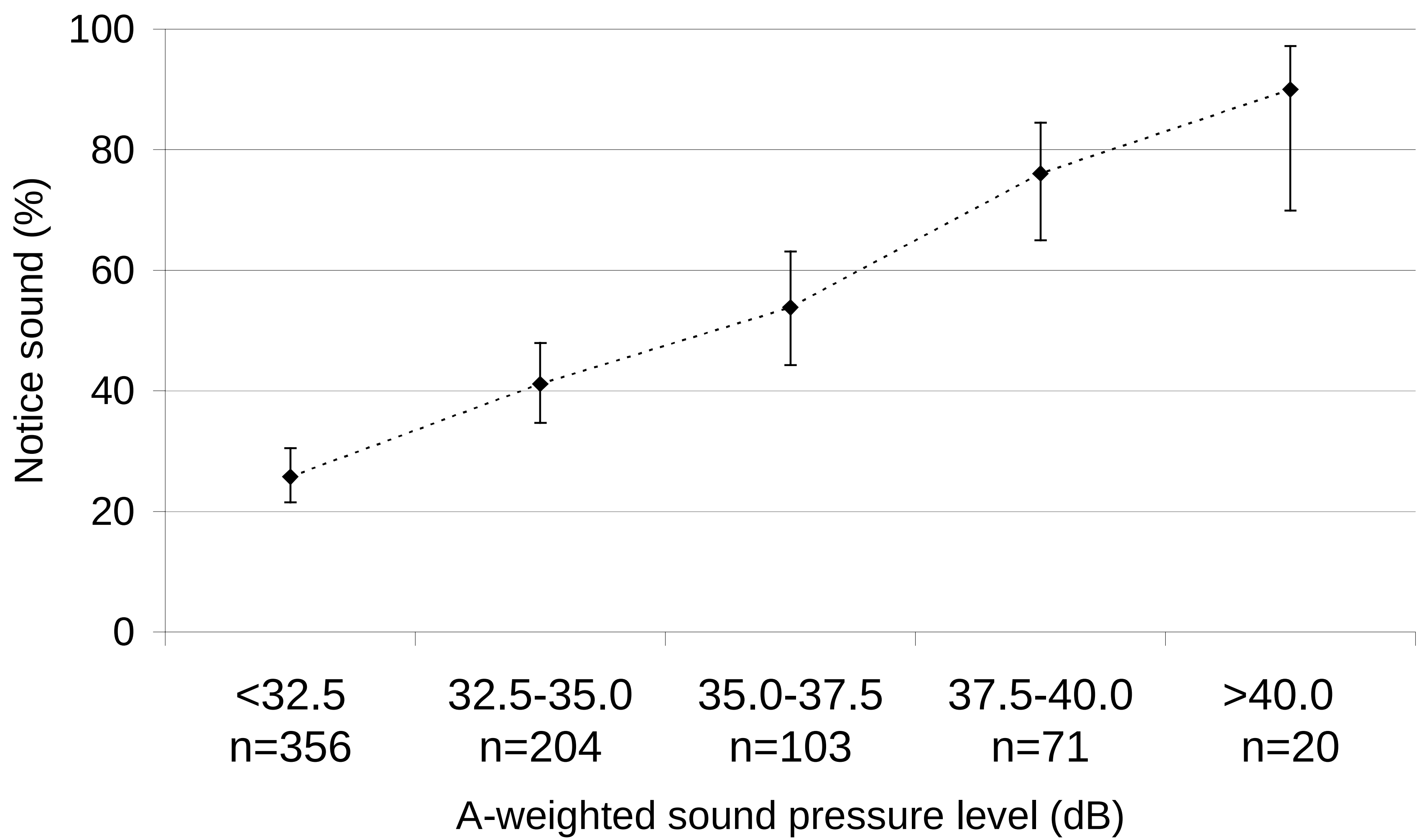
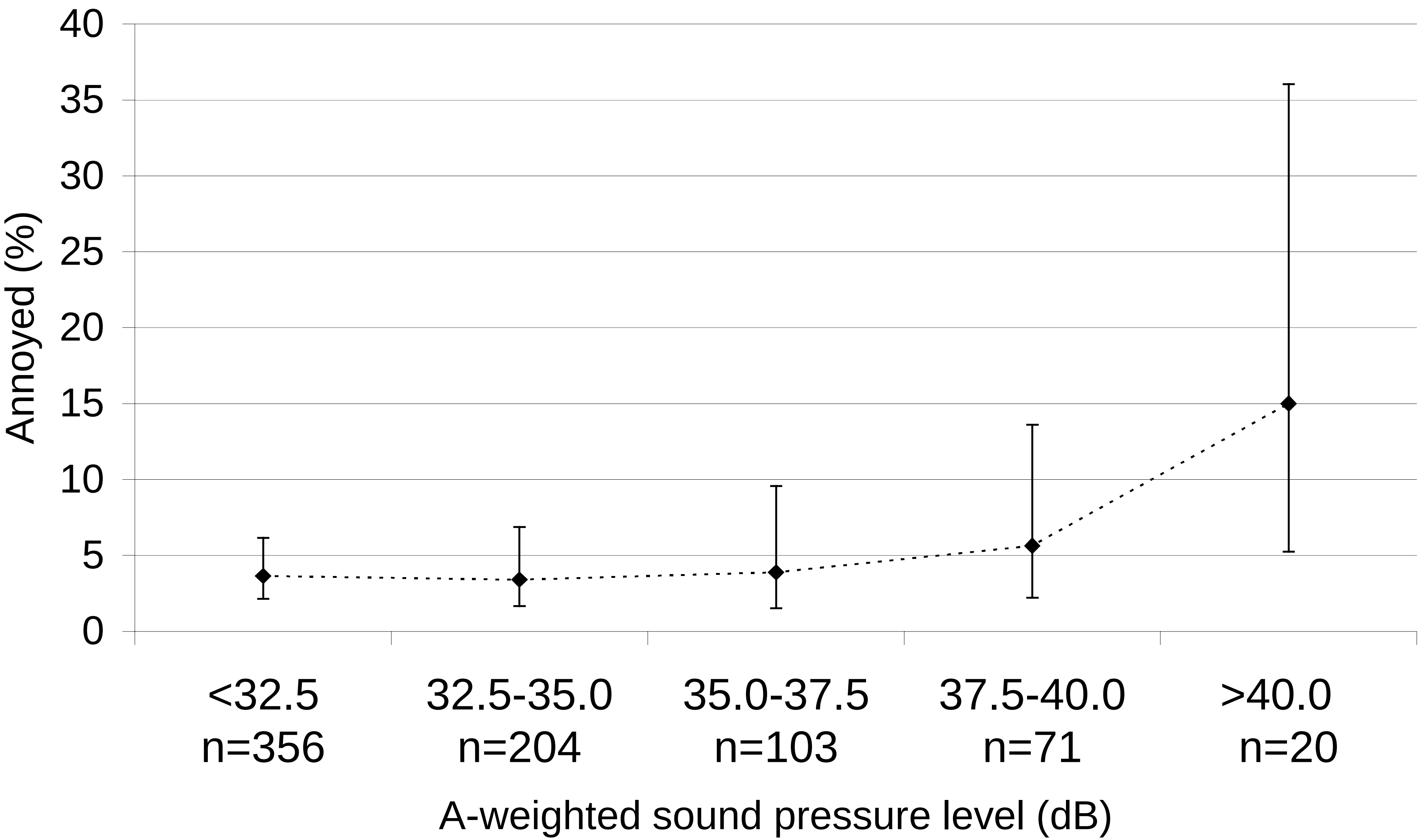
Figure 1. Proportion of respondents who noticed sound from wind turbines outside their dwelling, in relation to A-weighted sound pressure levels (SPLs) in 2.5-dB intervals. Vertical bars indicate 95% confidence intervals (CIs) and n = the total number of respondents in each interval.

Figure 2. Proportion of respondents who were annoyed by sound from wind turbines outside their dwelling, in relation to A-weighted sound pressure levels (SPLs) in 2.5-dB intervals. Vertical bars indicate 95% confidence intervals (CIs) and n = the total number of respondents in each interval.


100
80
60
40
20
0
Notice sound (%)
<32.5
n=356
32.5-35.0
n=204
35.0-37.5
n=103
37.5-40.0
n=71
>40.0
n=20
A-weighted sound pressure level (dB)


40
35
30
25
20
15
10
5
0
Annoyed (%)
<32.5
n=356
32.5-35.0
n=204
35.0-37.5
n=103
37.5-40.0
n=71
>40.0
n=20
A-weighted sound pressure level (dB)