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Effects of wind turbine noise on humans

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Abstract

Possible adverse health effects due to exposure of wind turbine noise have been discussed since the first modern electrical generating wind turbines were erected in the 1970's. Despite this, only a few large epidemiological studies have been carried out. This paper is based on data from two Swedish studies and one Dutch study in which self-reported health and well-being were related to calculated A-weighted sound pressure levels outside the dwelling of each respondent. The consistencies in results from these studies make it possible to summarize the impact of wind turbine noise on people living in the vicinity of the turbines. The main adverse effect was annoyance due to the sound; the prevalence of noise annoyance increased with increasing sound pressure levels. Disturbance of sleep was furthermore related to wind turbine noise; the proportion of residents reporting sleep disturbance due to noise increased significantly at sound levels close to those recommended as highest acceptable levels at new installations. No other clear associations between sound levels and self reported health symptoms have hitherto been found. However, noise annoyance was correlated with several measurements of stress and lowered well-being. The study design does not allow causal conclusions, but the association indicates a possible hindrance of psycho-physiological restitution. Such a hindrance could in the long term lead to adverse health effects not detected hear.

Introduction

There has been a concern of possible adverse health effects caused by noise from wind turbines ever since the beginning of the modern wind power era in the 1970's. This concern could be due to a common scepticism towards new technique, but could also be traced to bad experiences. The first commercial machines did not just emit aerodynamic noise but also noise from the machinery giving them a reputation as noisy. Furthermore, some were designed as down wind turbines with rather high levels of noise in the low frequency range that was negatively appraised [Hubbard 1982]. The noise was therefore a large issue already thirty years ago. Special for wind turbines are also that they often are placed in rural settings considered as places with low exposure of environmental stressors. Technical induced noise could in such a setting, even when the levels are comparably low, be perceived as a potential health risk.

Several studies concerning the impact of wind farms on residents in wind farm areas are cited in the discussion regarding possible health effects that takes place for example on Internet. Few of these studies have however been published in scientific journals, i.e. they are not critically reviewed and accepted by scientists. As the issue of wind power involves political decisions leading to conflicts where health risks become an argument rather than a fact, it is important to study possible health effects unprejudiced. Conclusions should hence be drawn from well designed experimental or epidemiological studies that have been seriously examined.

The definition of health set up by WHO 1948 is still the guiding principle in public health work. The definition reads as follows:

> Health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity [WHO 1948].

Such a definition implicates that when studying the effects of an environmental exposure it is necessary to not just focus on diseases or symptoms of impaired health, but also measure well-being in a wider sense. Response to noise such as annoyance is hence, in the light of the WHO definition, in it self a negative effect that should be avoided in order to retain well-being. However, annoyance could also be viewed upon as a measurable indicator of enhanced risk for chronic unbalance in the physiological stress system; an unbalance that could lead to more severe states such as high blood pressure and, if prolonged, to more severe cardio-vascular diseases. The theory has been confirmed in studies where an association between high exposure of community noise, such as road traffic and aircraft noise, and high blood pressure has been found [e.g. Barregard *et al.* 2009]. The exposure levels were in these traffic studies higher than those relevant for residents living in the vicinity of wind turbines, but it can not be excluded that strong feelings of annoyance, despite sound levels, play a role in endocrine influenced diseases, possibly as inhibitors of physiological restitution [Åkerstedt and Nilsson 2003].

The public concern regarding possible health risks among people living in the vicinity of wind turbines should be treated seriously. The objective of this paper was to explore the relationship between wind turbine noise and potential adverse health effects using data from three epidemiological studies; two published and one soon to be published.

Included studies

All three studies were cross-sectional studies where levels of wind turbine noise were compared to self-reported health status among people living in wind farm areas. Study SWE-00 were carried out in a flat, rural landscape in the south of Sweden year 2000 [Pedersen and Persson Waye 2004]. Study SWE-05 also took place in Sweden but in areas that differed in population density and topography, including suburban sites and hilly terrain [Pedersen and Persson Waye 2007]. Study NL-07 was carried out in the Netherlands 2007, also in a flat landscape, but with different degrees of road traffic intensity [van den Berg *et al.* 2008]. Annoyance and other health effects were measured in postal questionnaires comprising questions of several potential environmental stressors to not lead the respondent towards a focus on wind turbine noise. The questionnaires were delivered during the summer months, i.e. when people supposedly spend time outdoors by their dwelling. A-weighted sound pressure levels (corresponding to downwind condition with wind speed 8 m/s at 10 m height) were calculated for each respondent from the sound power levels of all wind turbines nearby (logarithmically added). Two different algorithms were used for the calculations of the sound propagation; one for the Swedish studies [Swedish Environmental Protection Agency 2001] and another for the Dutch study [ISO 1996]. The algorithms give similar results at the distances relevant in these studies [van den Berg *et al.* 2008] and will therefore in these analyses be treated as correct estimations of the exposure for all respondents outside their dwelling.

The data sets have for this paper been re-analysed in order to assure similar treatment of the data. Only variables available from all three studies are included: response to noise (annoyance), diseases or symptoms of impaired health (chronic disease, diabetes, high blood pressure, cardiovascular disease, tinnitus, impaired hearing), stress symptoms (headache, undue tiredness, feeling tense or stressed, feeling irritable) and disturbed sleep (interruption of the sleep by any noise source), Variables measured in the questionnaires were answered either on binary scales (no/yes) or on ordinal 5-point scales. The latter was for example used for noise annoyance, with the scale "do not notice", "notice, but not annoyed", "slightly annoyed", "rather annoyed", and "very annoyed". The variable was for the analyses dichotomized into "not annoyed" (comprising "do not notice", "notice, but not annoyed" and "slightly annoyed") versus "annoyed" (comprising rather annoyed" and "very annoyed"). Sleep disturbance due to noise (any source) was measured differently in the three studies. In the Swedish studies, the scale used was binary (no/yes) while in the Dutch study the scale was related to how often sleep disturbance occurred. Sleep disturbance once a month or more often was in this study considered as sleep disturbance.

Several health symptoms are known to increase with age and also have different prevalence among males and females that has to be taken into account. Associations between A-weighted sound pressure levels and self-reported health were therefore tested with binary logistic regression as this method allows adjustments for known confounders. The Dutch study differed from the others in that many of the respondents in the samples with the highest exposures of wind turbine noise reported that they benefited economically from the wind turbines. Almost none of these respondents reported noise annoyance and they also differed from the rest; e.g. they were younger and overall healthier. The results from the Dutch study are therefore reported twice; once with adjusting for economical benefits. The outcome of a logistic regression is the odds ratio (OR) with a 95% confidence interval (95% CI). An OR above 1.00, with a 95% CI with the lower value also above 1.00, indicates a positive correlation between the dependent (health) and the independent variable (sound pressure levels) in the regression model.

A-weighted sound pressure levels were furthermore divided into 5-dB(A) intervals and compared with proportion of respondent annoyed by the noise and disturbed in their sleep by any noise source. Confidence intervals of the proportions were calculated in accordance with Wilson [Altman *et al.* 2000].

Results

A-weighted sound pressure levels were in all three studies related to annoyance with wind turbine noise outdoors (Table 1).

Table 1. Association between A-weighted sound pressure levels (independent, continuous variable) and symptoms of adverse health effects (dependent, binary variable) tested with logistic regression. Statistically significant associations in bold numbers.

	N	OR*	95% CI*
Annoyance (outdoors)			
SWE-00	333	**1.24**	**1.13 – 1.36**
SWE-05	744	**1.14**	**1.03 – 1.27**
NL-07	687	**1.10**	**1.06 – 1.15**
NL-07**	664	**1.18**	**1.12 – 1.24**
Chronic disease			
SWE-00	328	0.97	0.89 – 1.05
SWE-05	742	1.01	0.96 – 1.07
NL-07	697	0.97	0.95 – 1.00
NL-07**	672	0.98	0.95 – 1.01
Diabetes			
SWE-00	333	0.96	0.79 – 1.16
SWE-05	744	**1.13**	**1.00 – 1.27**
NL-07	703	0.97	0.90 – 1.06
NL-07**	678	1.00	0.92 – 1.03
High blood pressure			
SWE-00	333	1.03	0.90 – 1.17
SWE-05	744	1.05	0.97 – 1.13
NL-07	703	0.97	0.94 – 1.03
NL-07**	678	1.01	0.96 – 1.06
Cardiovascular disease			
SWE-00	333	0.87	0.68 – 1.10
SWE-05	744	1.00	0.88 – 1.13
NL-07	703	0.96	0.90 – 1.03
NL-07**	678	0.98	0.91 – 1.05
Tinnitus			
SWE-00	333	**1.25**	**1.03 – 1.50**
SWE-05	744	0.97	0.88 – 1.07
NL-07	703	0.94	0.86 – 1.03
NL-07**	678	0.94	0.85 – 1.04
Impaired hearing			
SWE-00	333	1.09	0.93 – 1.27
SWE-05	744	1.05	0.95 – 1.15
NL-07	703	0.98	0.93 – 1.07

NL-07**	678	1.01	0.94 – 1.10

*Adjusted for age and sex.
**Adjusted also for economical benefits.

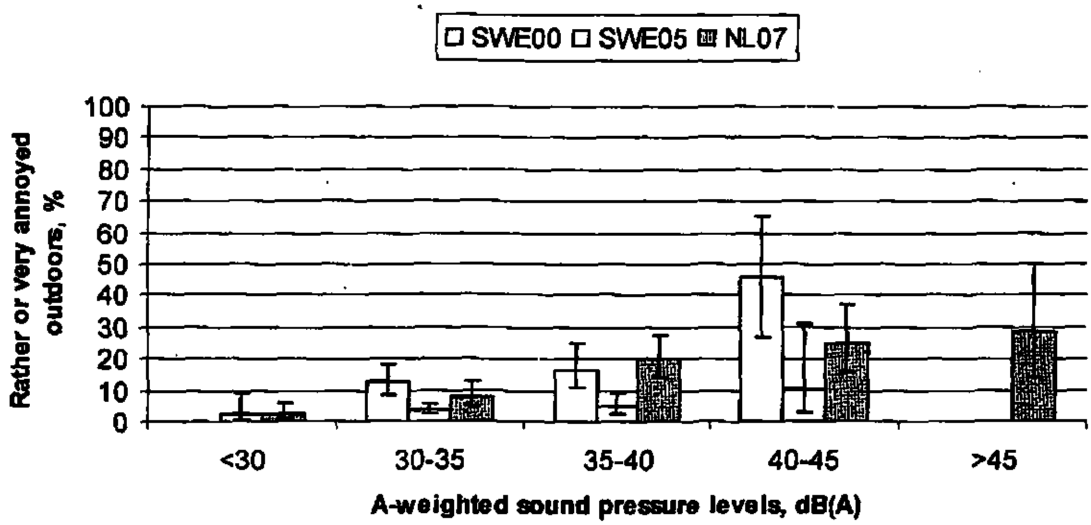

Figure 1. Relationship between A-weighted sound pressure levels (equivalent levels at wind speed 8 m/s, 10 m over the ground) and proportion of respondents rather or very annoyed by wind turbine noise outdoors in three studies: SWE00 (n = 341), SWE05 (n = 754) and NL07 (only respondents that did not benefit economically from wind turbines; n = 586).

The highest increase of annoyance with increase of sound levels was found in the first Swedish study, followed by the Dutch study when adjustments for economical benefits had been made. The prevalence of annoyance was similar in the first Swedish study and the Dutch study up to 40 dB(A) (the recommended highest level in Sweden), but then increased more in the Swedish study than in the Dutch study (Figure 1). Annoyance was low in all sound level intervals in the second Swedish study and differed statically significant from that in the two others studies in the sound level interval 35 – 40 dB(A).

No other variable measuring health or well-being was consistently related to A-weighted sound pressure level throughout the three studies (Table 1). The prevalence of tinnitus was in the first Swedish study positively related to sound pressure levels, but no such relationship was found in the other two studies. An indication of a positive relationship between the prevalence of diabetes and sound pressure levels was found in the second Swedish study. The lower limit of the confident interval was however just above 1.00.

No associations between A-weighted sound pressure levels and variables measuring symptoms of stress were found (Table 2).

Reports of interruption in the sleep by noise of any source were in the first Swedish study related to A-weighted sound pressure levels of wind turbine noise (Table 3). The same was found in the Dutch study when the analyses were adjusted also for economical benefits.

524

Table 2. Association between A-weighted sound pressure levels (independent, continuous variable) and symptoms of stress (dependent, binary variable) tested with logistic regression.

	N	OR*	95% CI*
Headache			
SWE-00	320	0.95	0.88 – 1.02
SWE-05	720	1.04	0.99 – 1.10
NL-07	661	1.00	0.97 – 1.02
NL-07**	639	1.01	0.98 – 1.04
Undue tiredness			
SWE-00	319	0.95	0.88 – 1.02
SWE-05	725	0.98	0.93 – 1.03
NL-07	662	0.99	0.96 – 1.01
NL-07**	639	1.02	0.99 – 1.05
Tense and stressed			
SWE-00	319	1.02	0.94 – 1.10
SWE-05	721	1.00	0.95 – 1.05
NL-07	663	0.99	0.97 – 1.02
NL-07**	641	1.01	0.98 – 1.04
Irritable			
SWE-00	319	1.03	0.96 – 1.11
SWE-05	724	1.00	0.96 – 1.06
NL-07	666	1.00	0.98 – 1.03
NL-07**	644	1.01	0.98 – 1.04

*Adjusted for age and sex.
**Adjusted also for economical benefits.

Table 3. Association between A-weighted sound pressure levels (independent, continuous variable) and sleep interruption (dependent, binary variable) tested with logistic regression. Statistically significant associations in bold numbers.

	N	OR*	95% CI*
Interrupted in the sleep by noise			
SWE-00	333	**1.12**	**1.03 – 1.22**
SWE-05	738	0.97	0.90 – 1.05
NL-07	703	1.01	0.99 – 1.04
NL-07**	678	**1.03**	**1.00 – 1.07**

*Adjusted for age and sex.
**Adjusted also for economical benefits.

52b

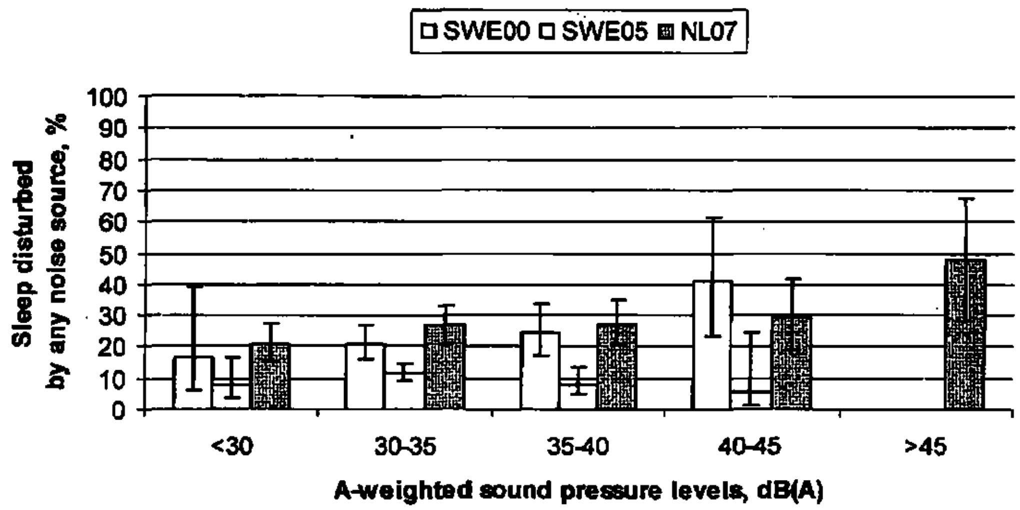

Figure 2. Relationship between A-weighted sound pressure levels (equivalent levels at wind speed 8 m/s, 10 m over the ground) and proportion of respondents disturbed in the sleep by noise in three studies: SWE00 (*n* = 341), SWE05 (*n* = 746) and NL07 (only respondents that did not benefit economically from wind turbines; *n* = 593).

In the first Swedish study the increase of respondents that reported sleep interruption appears to be between the sound level interval 35-40 dB(A) and 40-45 dB(A) (Figure 2). The increase came at higher sound levels in the Dutch study; between the interval 40-45 dB(A) and >45 dB(A).

Several of the variables measuring symptoms of stress were associated with annoyance due to wind turbine noise, also when adjusting for A-weighted sound pressure levels (Table 4). Feeling tense or stressed as well as irritable was associated with noise annoyance in all three studies. Headache was associated with annoyance in the first Swedish study and in the Dutch study. Undue tiredness was associated with annoyance only in one study. The study design do not allow conclusions of cause and effect; annoyance could lead to stress, or stress could enhance the risk for annoyance.

Table 4. Association between annoyance due to wind turbine noise (independent, 5-point scale) and symptoms of stress (dependent, binary variable) tested with logistic regression. Statistically significant associations in bold numbers.

	N	OR*	95% CI*
Headache			
SWE-00	320	**1.24**	**1.01 – 1.51**
SWE-05	720	1.04	0.86 – 1.26
NL-07	650	**1.24**	**1.04 – 1.48**
NL-07**	630	**1.25**	**1.04 – 1.50**
Undue tiredness			
SWE-00	319	**1.22**	**1.00 – 1.49**
SWE-05	725	1.12	0.93 – 1.35
NL-07	652	1.15	0.98 – 1.35
NL-07**	630	1.10	0.93 – 1.31
Tense and stressed			
SWE-00	319	**1.25**	**1.00 – 1.56**
SWE-05	721	**1.22**	**1.00 – 1.50**
NL-07	652	**1.28**	**1.08 – 1.50**
NL-07**	631	**1.27**	**1.07 – 1.50**
Irritable			
SWE-00	319	**1.36**	**1.10 – 1.69**
SWE-05	724	**1.22**	**1.00 – 1.49**
NL-07	666	**1.23**	**1.05 – 1.45**
NL-07**	644	**1.27**	**1.07 – 1.50**

*Adjusted for age, sex and A-weighted sound pressure levels.
**Adjusted also for economical benefits.

Concluding remarks

When a high amount of statistical tests are carried out, some will by random show significant relationships when there in fact are none; if a 95% confidence interval is chosen, theoretically 1 of 20 tests will result in a dubious outcome. Consistent results from three studies enhance the certainty. Annoyance was the only response to wind turbine noise measured in these studies that was directly associated with A-weighted sound pressure levels in all three studies. The increased risk for annoyance with increase in sound levels varied however between the studies. The highest increase in risk, and also the highest prevalence of annoyance at sound levels between 40 and 45 dB(A), was found in the first Swedish study that was carried out in a rural, flat landscape with possibly lower levels of background sound than in the two other studies. It is known from aircraft studies that annoyance response in low background noise regions are much higher than those in high background noise regions, even though aircraft noise levels are the same [Lim *et al.* 2008]. If this is actually due to the noise or to other qualities in the rural landscape is not clear. The prevalence of annoyance was high also in the Dutch wind turbine study; higher than in the second

Swedish study. Common for the first Swedish study and the Dutch study is the flat landscape where wind turbines often are visible in several direction and hence have a substantially impact on the landscape.

A rather high amount of respondents reported that their sleep was interrupted by noise, a nuisance that was found to be related to levels of wind turbine noise in two of the studies (and also to road traffic noise that was additionally measured in the Dutch study). The impact of noise did not increase gradually with noise levels, but rather with a sharp increase around 40 dB(A) in the first Swedish study and around 45 dB(A) in the Dutch study, corresponding well with the recommended highest exposure levels in the two countries. Sleep interruption was not common in the second Swedish study carried out mainly in more densely populated areas with suburban characteristics. It is not clear why sleep interruption was less common in these areas, but a combination of lowered expectations of quietness and higher levels of background noise (without incidents of heavy traffic at night) could be an explanation.

Stress was in these studies not directly associated with A-weighted sound pressure levels, but with noise annoyance. There was a remarkable consistency among the studies for the relationship between feeling tense or stressed and annoyance. This should however not be taken as evidence for a causal relationship from wind turbine noise to stress, mediated by annoyance. The finding could be explained in the light of Lazarus and Folkman's cognitive stress theory [1984] where an individual appraises an environmental stressor, such as noise, as beneficial or not, and act on behalf of this. An individual already in a strenuous situation possibly appraises the noise as an additional threat to psycho-physiological restoration. As in the present case wind turbine noise can not be controlled by the individual, no action can be taken and the response is manifested as annoyance. Being interrupted in the sleep could possibly further increase the feeling of wind turbine noise as a threat.

The results of the studies are not alarming, but call for political action and further research. Annoyance due to wind turbine noise should in the future be avoided by applying proper regulations for shortest distance between wind turbines and dwellings in the surroundings. Further scientific studies should explore the influence of wind turbine noise on sleep in different situations as well as the interaction between sound exposure, noise annoyance and stress.

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