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Wind turbine noise and health-related quality of life of nearby residents: a cross-sectional study in New Zealand.

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Abstract

Hearing allows humans to detect threats in the environment and to communicate with others. However, unwanted sound has the capacity to evoke reflexive and emotional responses, and can act a stressor. The World Health Organisation classifies noise as an environmental pollutant that degrades sleep, quality of life and general health. Previous research provides evidence of a relationship between wind turbine noise and both annoyance and sleep disturbance. However, wind turbines are a relatively new source of community noise, and as such their effects on health have yet to be fully described. We report a study exploring the effect of wind turbine noise on health and well-being in a sample of New Zealand residents living within two kilometres of a wind turbine installation. Our data provide evidence that wind turbine noise can degrade aspects of health-related quality of life and amenity. On this evidence, wind turbine installations should be sited with care and consideration with respect to the communities hosting them.

Introduction

Wind turbines transform wind energy into electricity. Over the last decade, the industrial-scale harvesting of wind energy has increased, driven by a desire to generate sustainable energy. Wind turbines were initially welcomed by communities, but public opposition to wind turbines has since increased,[1] largely because of the noise they produce and also their visual impact.

There has been considerable debate over whether wind turbines pose a significant health threat to those living in their vicinity. It has been suggested that wind turbines can directly impact health via the emission of low-frequency sound energy (i.e. infrasound), though this is currently an area of controversy.[2, 3]Additionally, wind turbines may compromise health by producing sound that is annoying and/or can disturb sleep. In this respect, it can be classified as community noise along with industrial and transportation noise. When built in rural settings, the visual impact of turbines can also degrade amenity and interact with turbine noise to exacerbate annoyance reactions.[4]

Figure 1 represents a simple model informed by the literature [5, 6] demonstrating that, in the rural context, there are feasible mechanisms by which wind turbine exposure can degrade health and well-being. Turbine noise can lead directly to annoyance and sleep disturbance (primary health effects), or can induce annoyance by degrading amenity. Additionally, the trait of noise sensitivity (being likely to attend to sound, evaluate sound negatively, and have stronger emotional reactions to noise) constitutes a risk factor. The secondary heath effects would be immediate reductions in general well-being and stress-related disease emerging from chronic annoyance and sleep disturbance. Chronic noise exposure is a psychosocial stressor that can induce maladaptive psychological responses and negatively impact health via interactions between the autonomic nervous system, the neuroendocrine system, and the immune system.[6] A chronic stress response will, in turn, degrade quality of life (Figure 1).

Quantifying the impact of wind turbines on individual health will inform wind turbine operational guidelines. One approach to health assessment involves a subjective appraisal of Health-Related Quality of Life (HRQOL), a concept that measures general well-being and well-being in the physical, psychological, social, and environmental domains. The WHO recommends the use of HRQOL measures as an outcome variable, arguing that the effects of noise are strongest for those outcomes classified under HRQOL rather than illness.[7] HRQOL is related to health by the WHO (1948) definition of health as “a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity”, and can be considered as an operationalisation of the well-being concept.[8]

There is scientific evidence linking community noise to health problems.[6, 7, 8] The WHO reports that chronic noise-induced annoyance and sleep disturbance can compromise health and HRQOL.[7, 9, 10] However, there has been little research examining the relationship between noise and HRQOL. An exception is Dratva et al.,[11] who, using the Short Form (SF36) health survey, reported an inverse relationship between annoyance from traffic noise and HRQOL. They argued that HRQOL would be expected to co-vary more with annoyance than with noise level as level is a poor predictor of the human response to noise, and its role in health is commonly over-emphasised. As alternatives to noise level, other factors associated with the listener should be considered,[5] including the perceived control a person has over the noise, as well as their attitudes, personality, and age.

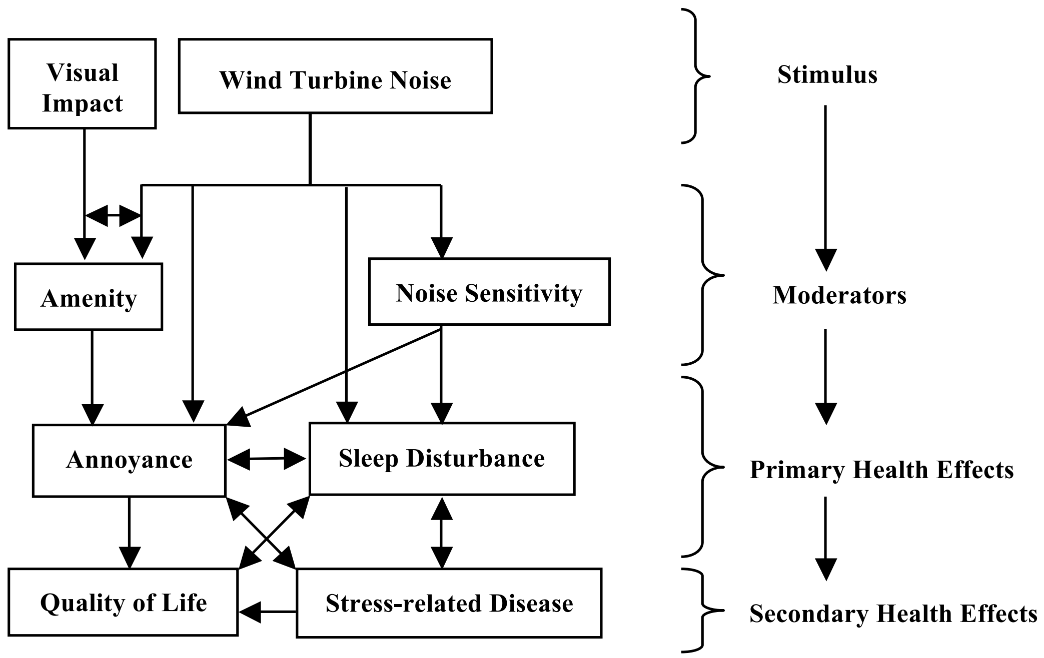

Figure 1 A schematic representation of the relationship between wind-turbines and health in a rural setting. The multiplicity of relationships emerges due to variability in the response of individuals to noise.

Case studies supported by qualitative analyses [2, 12, 13] suggest a negative relationship between wind turbine noise and wellbeing. There have been no previous quantitative investigations of the impact of wind turbines on HRQOL, though correlations have been observed between wind turbine noise, annoyance, and sleep disruption.[14, 15] Our study is the first to examine the association between HRQOL and the proximity to an industrial
wind turbine installation.

Method

A non-equivalent comparison group posttest-only study design was utilised. Strict socioeconomic matching was undertaken using the New Zealand Deprivation Index 2006,[16] as described elsewhere.[17] Both areas are classified as rural,[18] with a population density of less than 15 people per square kilometre.

Samples were drawn from two demographically matched areas differing only in their distances from a wind turbine installation in the Makara Valley, an area 10 kilometres west of New Zealand's capital city, Wellington. The Makara Valley is characterised by hilly terrain, with long ridges running 250 – 450 metres above sea level, on which sixty-six 125-metre-high wind turbines are positioned. The first sample (the Turbine group) was drawn from residents in the South Makara Valley who resided in 56 houses located within two kilometres of a wind turbine. A comprehensive noise survey of the area was undertaken independently, and indicated the intrusive nature of the turbine noise.[19] The Makara turbines, operational since May 2009, have measured levels that are consistent with levels reported in European studies,[15] which showed that typical noise exposures from wind turbines ranged from between 24 and 54 dB(A). The second sample (the Comparison group) was taken from residents in 250 houses in a geographically and socioeconomically matched area, but which were located at least eight kilometres from any wind turbine installation.

Each house received two copies of the questionnaire. The coversheet of the questionnaire bore the title 2010 Wellbeing and Neighbourhood Survey, designed to mask the true intent of the study. Potential participants were invited to participate in the research investigating their place of living and their wellbeing if they resided at the address to which the questionnaire had been delivered and if they were 18 years or older. The order of the questions was a prime consideration: HRQOL (26 items), amenity (2 items), neighbourhood problems (14 items), annoyance (7 items) demographic information (7 items), and a single item probing noise sensitivity. All scale items were presented on a numbered five-point scale with appropriate descriptors anchoring the terminals. Self-reported HRQOL was measured using the abbreviated version of the WHOQOL-BREF which affords composite measures of Physical (7 items), Psychological (6 items), Social (3 items) and Environmental (8 items) HRQOL. Additionally, the WHOQOL-BREF has two generic items asking about general health and overall quality of life. The two amenity items were: "I am satisfied with my neighbourhood / living environment" and "My neighbourhood / living environment makes it difficult for me to relax at home". A modified neighbourhood problem scale [20] consisted of 14 distracter items that were not relevant to the current study and were not included in the analysis. Seven items on annoyance were included, 4 distracter items asking about air quality, and 3 items probing annoyance to traffic, other neighbours, or other noise (please specify). Additionally, participants were asked if they were not noise sensitive, moderately noise sensitive, or very noise sensitive. The questionnaire terminated with an open-ended item asking "If you would like to share any comments relating to your neighbourhood or this survey then please do so in the box below". Participants were asked to respond to all items and to return surveys by post in the prepaid envelopes provided.

Self-reported age and sex measures were obtained and self-reported level of educational status used as an indicator of socioeconomic status. Additionally, participants were asked what their current employment status was, and whether they were currently ill or had a medical condition. Participants were also asked how long they had lived at their current residence.

Analysis commenced after an evaluation of each scale's psychometric properties, including inspection for floor and ceiling effects and tests of internal consistency (Cronbach's alpha) and to validate dimensionality (corrected item-total correlations). Differences in HRQOL and amenity between the Turbine and Comparison groups were calculated using univariate Analysis of Covariance (ANCOVA), with length of residence selected a priori as a covariate. All testing was undertaken in accordance with Tabachnick and Fidell's [21] guidelines for testing between groups with unequal sample sizes, and Bonferroni corrections were applied where appropriate. Because of the unequal sizes between the two groups the assumptions of normality and homogeneity of variance were assessed carefully. Five cases were excluded from the Comparison group because they were multivariate outliers as defined by extreme Mahalanobis distances, with response set acquiescence clearly evident in all five cases.

Results

The response rates, 34% and 32% from the Turbine and Comparison groups, respectively, were typical for this type of research (e.g., van den Berg and colleagues' (2008) report a 37% response rate). Table 1 presents demographic information for the Comparison and Turbine groups. Prior to analyses the data were screened to identify potential confounds. The proportions of males and females in each area were equivalent (χ^2 (1) = .001, p = .967), while a Mann Whitney U indicated no age difference between the two areas (U(n1= 158 , n2 =39) = 16022.5, p = .802). Education (χ^2 (2) = 2.474, p = .291), noise sensitivity (χ^2 (2) = .553, p = .758), and self-reported illness (χ^2 (1) = .414, p = .562) were not associated with area.

Table 1 Demographic profile of the Turbine and Comparison groups

Variables	**Turbine Group (*n*=39)** *n* (%)	**Comparison Group (*n*=158)** n^* (%)
Sex		
Male	16 (41)	63 (41)
Female	23 (59)	91 (58)
Age group, years		
18 – 20	1 (2.6)	2 (1.2)
21 – 30	1 (2.6)	1 (0.5)
31 – 40	5 (12.8)	22 (13.9)
41 – 50	10 (25.6)	53 (33.5)
51 – 60	11 (28.2)	44 (27.8)
61 – 70	7 (17.9)	27 (17.1)
71+ –	3 (7.7)	9 (5.6)
Education (completed)		
High School	11 (28.2)	55 (34.8)
Polytechnic	11 (28.2)	48 (30.3)
University	17 (43.6)	54 (34.2)
Employment status		
Full time	21 (53.8)	83 (52.5)
Part time	0 (0)	3 (1.8)
Unpaid work	1 (2.6)	3 (1.8)
Unemployed	6 (15.3)	27 (17.1)
Retired	10 (25.6)	40 (25.3)
Noise sensitivity		
None	13 (33.3)	60 (37.9)
Moderate	21 (55.3)	76 (48.1)
Severe	5 (12.8)	20 (12.7)
Current illness		
Yes	10 (27)	50 (31.6)
No	27 (69.2)	104 (65.8)

Table 2 Pearson product-moment correlation coefficients (*r*) for noise-related and HRQOL variables. Statistics to the right of the major diagonal are for the Comparison group, while those to the left are for the Turbine group

					Health-Related Quality of Life				
	Sensitivity	Annoyance	Sleep	Health	Physical	Psychological	Social	Environment	Overall
Sensitivity	1	0.134	-0.017	0.082	-0.017	-0.069	0.006	-0.066	-0.109
Annoyance	0.440**	1	.042	-0.258**	-0.209*	-0.135	-0.155*	-0.319**	-0.097
Sleep	-0.433**	-0.147	1	0.337**	0.378**	0.489**	0.327**	0.279**	0.198*
Health	-0.234	-0.308	0.471**	1	0.706**	0.493**	0.158*	0.284**	0.327**
Physical§	-0.24	-0.212	0.364*	0.524**	1	0.655**	0.29**	0.455**	0.475**
Psychological	-0.404*	-0.113	0.473**	0.329*	0.268	1	0.55**	0.608**	0.589**
Social	-0.359*	-0.236	0.116	-0.021	0.036	0.212	1	0.456**	0.457**
Environment	-0.235	0.028	0.404**	0.2	0.474*	0.468*	-0.17	1	0.546**
Overall	-0.203	0.16	0.471**	0.289	0.282	0.286	-0.162	0.380*	1

$p < .05$

** $p < .001^*$

§ Item 16 (satisfaction with sleep) was removed from the Physical HRQOL domain when correlated with sleep satisfaction.

Table 2 displays correlation coefficients (Pearson's *r*) between noise-related and health-related variables for both groups. Of remark is the negative correlation between annoyance and self-rated health for both groups, and a different pattern of correlations between noise sensitivity and annoyance across the two groups. Separate ANCOVA's revealed differences and similarities between the two areas in terms of HRQOL (see Table 3). Firstly, the Turbine group reported a lower ($F(1,194) = 5.816$, $p = .017$) mean physical HRQOL domain score than the Comparison group. Scrutiny of the seven facets of the physical domain showed a difference in perceived sleep quality between the two areas ($t(195) = 3.089$, $p = .006$), and between self-reported energy levels ($t(195)= 2.217$, $p = .028$). Secondly, the Turbine group had lower ($F(1,194) = 5.694$, $p = .018$) environmental HRQOL scores than the Comparison group. This domain is the sum of eight items, and further analysis of these revealed that the turbine group considered their environment to be less healthy ($t(195)= 3.272$, $p < .007$) and were less satisfied with the conditions of their living space ($t(195)= 2.176$, $p = .031$). Thirdly, there were no statistical differences in social ($F(1,194) = 0.002$, $p = .963$) or psychological ($F(1,194) = 3.334$, $p = .069$) HRQOL, although the latter was marginal and the mean for the Turbine group was lower. Of the two generic WHOQOL-BREF items, the mean of the self-rated general health item was equivalent between Turbine and Comparison groups ($t(195) = 0.374$, $p = .709$), while the mean ratings for an overall quality of life item was lower ($t(195) = 2.364$, $p = .019$) in the Turbine group.

Table 3 Mean (M) and Standard Deviation (SD) statistics for the four HRQOL domains of the WHOQOL-BREF and Amenity total scores, presented for both the Comparison group and the Turbine group

	Turbine Group		*Comparison Group*	
Measure	*M*	*SD*	*M*	*SD*
Physical	27.38	3.14	29.14	3.89
Psychological	22.36	2.67	23.29	2.91
Social	12.53	1.83	12.54	2.13
Environmental	29.92	3.76	32.76	4.41
Amenity	7.46	1.42	8.91	2.64

The Turbine group reported lower amenity than the Comparison group ($F(1,194) = 18.88$, $p < .001$). There were no differences between groups for traffic ($t(195) = 0.568$, $p = .154$) or neighbourhood ($t(195) = 1.458$, $p = .144$) noise annoyance. A comparison between ratings of turbine noise was not possible, but the mean annoyance rating for Turbine group individuals who specifically identified wind turbine noise as annoying was 4.59 (SD = 0.65), indicating that the turbine noise was perceived as extremely annoying. For the Comparison group, seven 'other' annoying noises were identified: barking dogs (x2), farm machinery (x2), and racing cars (x3).

Discussion

Those residing in the immediate vicinity of wind turbines scored worse than a matched comparison group in terms of physical and environmental HRQOL, and HRQOL in general. The high incidence of annoyance from turbine noise in the Turbine group is consistent with the theory that exposure to turbine noise is the cause of these differences. Importantly, we also found a reduction in sleep satisfaction ratings, suggesting that both annoyance and sleep disruption may mediate the relationship between noise and HRQOL. These findings are consistent with those reported in relation to aviation noise [22] and traffic noise.[10, 11]

Of further interest are the likely mechanisms involved in the degradation of HRQOL when exposed to turbine noise. Studies show that the level of turbine noise is a poor predictor of human response, and dose-response relationships typically explain little of the association between turbine noise and annoyance.[23] Pedersen et al.[4, 23] and van den Berg et al.[15] show that for equivalent noise levels, people judge wind turbine noise to be of greater annoyance than aircraft, road traffic, or railway noise. This may be due to the unique characteristics of turbine noise, that is, clusters of turbines present a cumulative effect characterized by a dynamic or modulating sound as turbines synchronise. The characteristic swishing or thumping noise associated with larger turbines [19] is audible over long distances, 2 to 3 kilometres and beyond in some reports.[1]

van den Berg [15] showed that sound is the most annoying aspect of wind turbines, and is more of a problem at night. A large proportion (23/39) of respondents from the Turbine group identified turbine noise as a problem and rated it to be extremely annoying. It should be noted that, in contemporary medicine, annoyance exists as a precise technical term describing a mental state characterised by distress and aversion, which if maintained, can lead to a deterioration of health and wellbeing.[24] A Swedish study [23] reported that, for respondents who were annoyed by wind turbine noise, feelings of resignation, violation, strain, and fatigue were statistically greater than for respondents not annoyed by turbine noise. We also observed lower sleep satisfaction in the Turbine group than in the Comparison group, a finding which is consistent with previous research showing more sleep disturbances. [2, 4, 15]

Wind turbines were associated with degraded amenity. This is consistent with previous research showing that wind turbine noise was judged incongruent with the natural soundscape of the area.[23] Amenity values are based upon what people feel about an area, its pleasantness, or some other value that makes it a desirable place to live. There is an expectation of “peace and quiet” when living in a rural area, and most choose to live in rural areas for this reason. [1, 25] Furthermore, those who live in rural areas have different expectations about community noise than those living elsewhere.[4] Other studies [26, 27] report that wind turbines are viewed as eyesores and visual spoilers of the environment, and from an aesthetic perspective, those who view the wind turbines as ugly are likely to disassociate them from the landscape and react more strongly to turbine noise.

Strengths and limitations

A strength of this study is the masking of the primary intent of the questionnaire by giving the impression that general neighbourhood factors (e.g., street lighting, rubbish collection), and not wind turbine exposure, constituted the study's core aims. Concealing the study's objectives should reduce response bias, and our placing of the HRQOL items at the beginning of the survey, well before the three items probing noise annoyance, would serve to elicit subjective ratings of HRQOL without first being primed with potentially upsetting noise items. The main limitation of the study is the size of the sample. While the response rate compares favourably to other wind turbine research reported in the literature,[15] the sparsely populated locations of wind turbine farms in rural New Zealand presents a recruitment challenge. A larger sample of residents exposed to wind turbines would have afforded more analytical options. However, that the effects were found with such a modest sample size is indicative of genuine differences between the two groups.

Assessing health using HRQOL rather than objective metrics such as blood pressure has it advantages and disadvantages, though the merits of the HRQOL approach have been noted by others researching air pollution.[28] While blood pressure and heart attacks are well defined and easily measured, sleep disturbance, fatigue, annoyance and similar subjective symptoms are less easily measured and distinguished from the background levels present in the population, and furthermore, may change only after decades of exposure .[7]

Conclusions

A thorough investigation of wind turbine noise and its effects on health is important given the prevalence of exposed individuals, a non-trivial number that is increasing with the popularity of wind energy. For example, in the Netherlands it is reported that 440,000 inhabitants (2.5% of the population) are exposed to significant levels of wind turbine noise.[29] Additionally, policy makers are demanding more information on the possible link between wind turbines and health in order to inform setback distances. Our results suggest that utility-scale wind energy generation is not without adverse health impacts on nearby residents. Thus, nations undertaking large-scale deployment of wind turbines need to consider the impact of noise on the HRQOL of exposed individuals. Along with others,[30] we conclude that night-time wind turbine noise limits should be set conservatively to minimise harm, and, on the basis of our data, suggest that setback distances needs to be greater than two kilometres.

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