Adverse health effects of industrial wind turbines: a preliminary report

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INTRODUCTION

Guidelines and regulations for the siting of industrial wind turbines (IWT) close to human habitation are generally predicated on the need to protect the sleep of the residents. The recommended setback distances and "safe" external noise levels make the assumptions that IWT noise can be regarded as similar to other forms of environmental noise (traffic, rail and aircraft) and is masked by ambient noise. There has been no independent verification that these assumptions are justified and that the safeguards are sufficient to protect sleep.

Anecdotal complaints of annoyance and health effects from IWT noise have grown in number in recent years, not least because turbine size has increased and they have been placed closer to population centers. The predominant symptom of health complaints is sleep disturbance (Frey & Hadden 2007; Pierpont 2009; van den Berg et al. 2008; WindVOICe 2010). The consequences of sleep disturbance and the contribution of environmental noise are well documented (WHO 2009).

Complaints of adverse health effects were made shortly after IWT installations at Mars Hill and Vinalhaven, Maine, USA, began operating. A preliminary survey at Mars Hill, comparing those living within 1,400 m with a control group living 3,000-6,000 m away showed that sleep disturbance was the main health effect (Nissenbaum 2011, submitted for publication). A further study was therefore carried out at both Mars Hill and Vinalhaven using validated questionnaires and comparing those living within 1.5 km of the turbines with a control group living 3,500-6,000 m away.

METHODS

General study design

A questionnaire was offered to all residents meeting inclusion criteria living within 1.5 km of an IWT and to a random sample of residents meeting inclusion criteria living 3 to 7 km from an IWT between March and July of 2010. The protocol was reviewed and approved by IRB Services, Aurora, Ontario, Canada.

Questionnaire

The questionnaire comprised validated instruments relating to mental and physical health (SF-36v2) (QualityMetric Inc.), sleep disturbance (Pittsburgh Sleep Quality Index (PSQI) (Buysse et al. 1989) and the Epworth Sleepiness Scale (ESS) (Johns 1991), in addition to headache functional inquiry questions and a series of attitudinal questions relating specifically to changes with exposure to IWT noise. Only the results from the validated instruments are presented here.

Participant selection

The Mars Hill site is a linear arrangement of 28 General Electric 1.5 megawatt turbines, sited on a ridgeline. The Vinalhaven site is a cluster of three similar turbines, sited on a flat tree covered island. All residents living within 1.5 km of an IWT at each site were identified via tax maps, and approached either door to door or via telephone and asked to participate in the study. Homes were visited up to three times or until contact was made. Those below the age of 18 or with a diagnosed cognitive disorder were excluded. A random sample of households in a similar socioeconomic area 3 to 7 km away from IWTs at each site was chosen to participate in the study as a control group. Households were approached door-to-door until a similar number of participants were enrolled.

Data handling and validation

Questionnaire results were coded and entered into a spreadsheet (Microsoft Excel 2007). The distance from each participant's residence to the nearest IWT was measured using satellite maps. SF36-V2 responses were processed using QualityMetric Health Outcomes™ Scoring Software 3.0 to generate Mental (MCS) and Physical (PCS) Component Scores. Missing values were verified and outliers were individually assessed. Data quality of the SF36-V2 responses was determined using QualityMetric Health Outcomes™ Scoring Software 3.0. All SF36-V2 data quality indicators (completeness, response range, consistency, estimable scale scores, internal consistency, discriminant validity, and reliable scales) exceeded parameter norms.

Statistical analysis

All analyses were performed using SAS 9.22. Descriptive and multivariate analyses were performed to investigate the effect of the main independent variable of interest (distance to nearest IWT) on the various outcome measures.

Significance of binomial outcomes was assessed using either the GENMOD procedure with binomial distribution and logit link; or when cell frequencies were small (<5), Fisher's Exact Test. When assessing significance between variables with a simple score as the outcome (eg. 1-5), the exact Wilcoxson Score (Rank Sums) test was employed using the NPAR1WAY procedure. Significance of continuous outcome variables was assessed using the GENMOD procedure with normal distribution. When using the GENMOD procedure, age, gender and site were forced into the model as fixed effects. The potential effect of household clustering on statistical significance was accommodated by using the REPEATED statement.

Independent variables assessed included the following: Site (Mars Hill, Vinalhaven); Distance to IWT (both as a categorical and continuous variable); Age (continuous variable); Gender (categorical variable). Significance of Site as an effect modifier was assessed by fitting an interaction term (Site*distance).

Dependent variables assessed include the following: Epworth Sleepiness Scale (ESS), Pittsburgh Sleep Quality Index (PSQI), SF36-v2 Mental Component Score (MCS), SF36-v2 Physical Component Score (PCS).

For the purpose of interpreting statistical significance, the following were used: P-value < 0.05 = Significant; P-value 0.1 – 0.05 = Moderately significant; P-value > 0.1 = Not significant

learn more about the SF36-v@ Physical Component Scores (PCS); they found no difference here, and the scores are not reported below; what factors contribute to these PCS scores?

Effect of Site on outcome parameters

The effect of Site was assessed by fitting Site (Mars Hill vs Vinalhaven) as a fixed effect, and as an interaction term with the main independent variable of interest (distance). Among all outcomes investigated, Site, and Site*Distance were not significant.

RESULTS

Study participants

lower response rate at Vinalhaven

33 and 32 adults were identified as living within 1,500 m of the nearest IWT at the Mars Hill (mean. 805 m, range 390-1,400) and Vinalhaven sites (mean 771 m range 375-1,000) respectively. 23 and 15 adults at the Mars Hill and Vinalhaven sites respectively completed questionnaires. Recruitment of control group participants continued to approximately the same number as study group participants, 25 and 16 for Mars Hill and Vinalhaven respectively.

There were no significant differences between the groups with respect to household size, age, or gender (Table 1).

Table 1: Demographic data

	Distance range from residence to nearest IWT (mean) in meters			
Parameter	375-750 (601)	751-1,400 (964)	3,300-5,000 (4,181)	5,300-6,600(5,800)
Sample size	18	20	14	27
Household clusters	11	12	10	23
Mean age	50	57	65	58
Male/Female	10/8	12/8	7/7	11/16

Sleep quality and health

The study group had worse sleep as evidenced by significantly higher mean PSQI and ESS scores and a greater number with PSQI >5 (Table 2). More subjects in the study group had ESS scores >10 but the difference did not reach statistical significance (p=0.1313).

The study group had worse mental health as evidenced by significantly higher mean mental component score of the SF36. There was no difference in the physical component scores.

Table 2: Sleep and mental health parameters

Parameter	Distance to IWT: Range (mean) m		p
	375-1,400 (792)	3,000-6,600 (5,248)	
PSQI Mean (LSmean)	7.8 (7.6)	6.0 (5.9)	0.0461
% PSQI >5	65.8	43.9	0.0745
ESS Mean (LSmean)	7.8 (7.9)	5.7 (5.7)	0.0322
% ESS >10	23.7	9.8	0.1313
SF36 MCS Mean (LSmean)	42.0 (42.1)	52.9 (52.6)	0.0021

ESS, PSQI and SF36 scores were modeled against distance from the nearest IWT using the equation: Score = ln(distance) + gender + age + site [controlled for household clustering] and are shown in Figures 1-3. In all cases, there was a clear and significant relationship with the effect diminishing with increasing distance from the IWT.

?:
is each plotted dot a single response, or are some an average of 2 or more responses from identical distances?
(it would be good to see full scatter; if this IS the full scatter, it's incredibly related to distance)

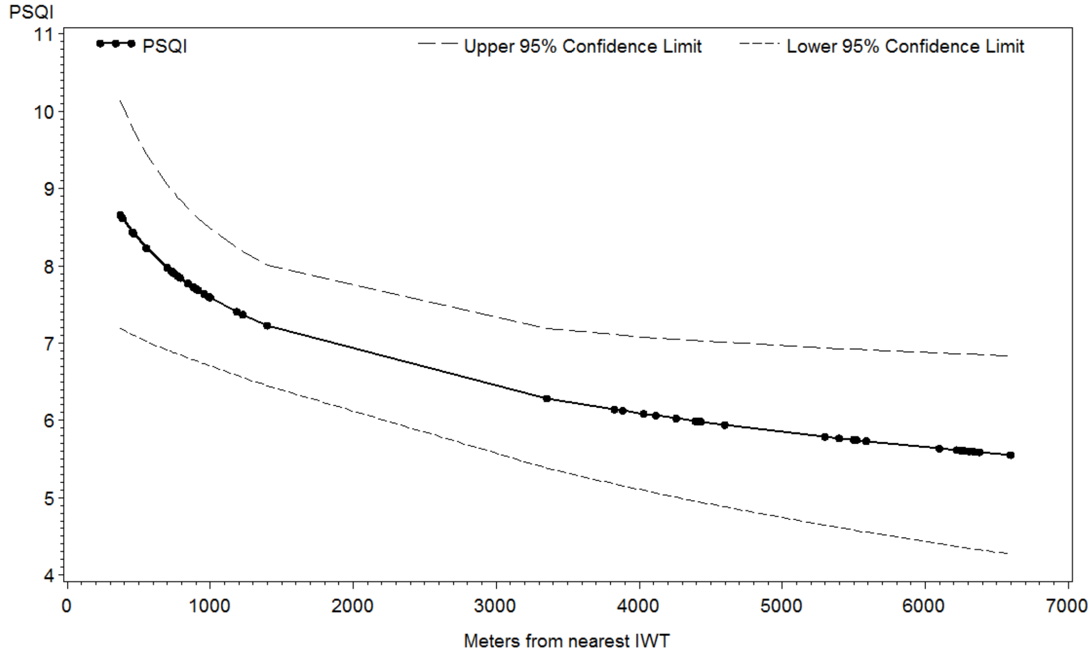

Figure 1: Modeled Pittsburgh Sleep Quality Index (PSQI) vs Distance (mean and 95 % confidence limits), p-value=0.0198

why is there a continued and consistent reduction in PSQI and ESS scores from 4km to 7km?

Is there any suggestion that turbines are audible at that range? (would seem unlikely)

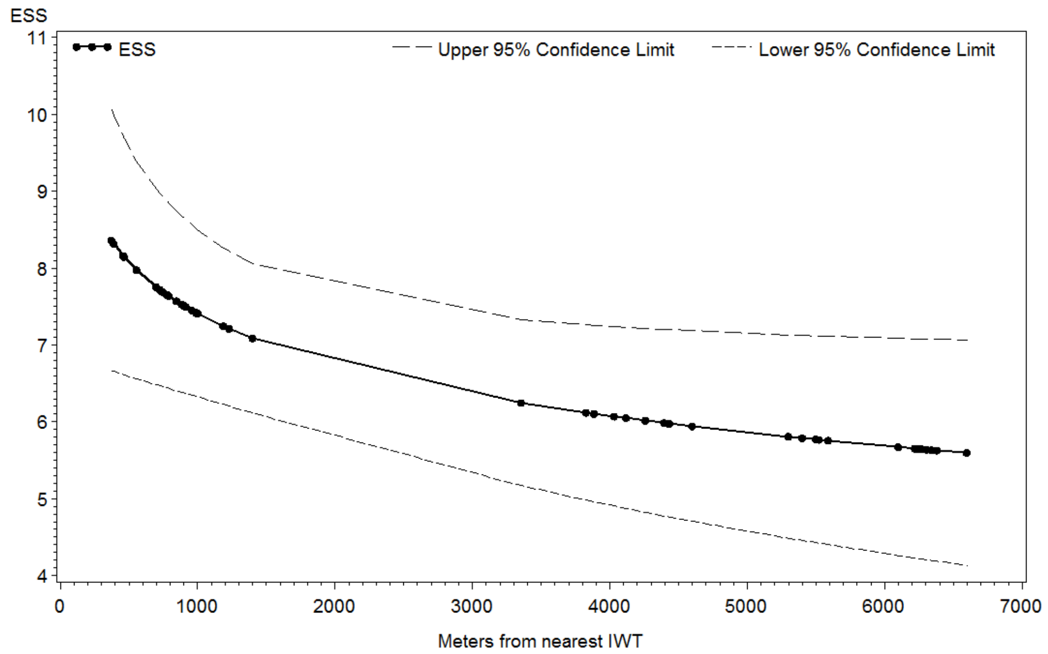

Figure 2: Modeled Epworth Sleepiness Scale (ESS) vs Distance (mean and 95 % confidence limits), p-value=0.0331

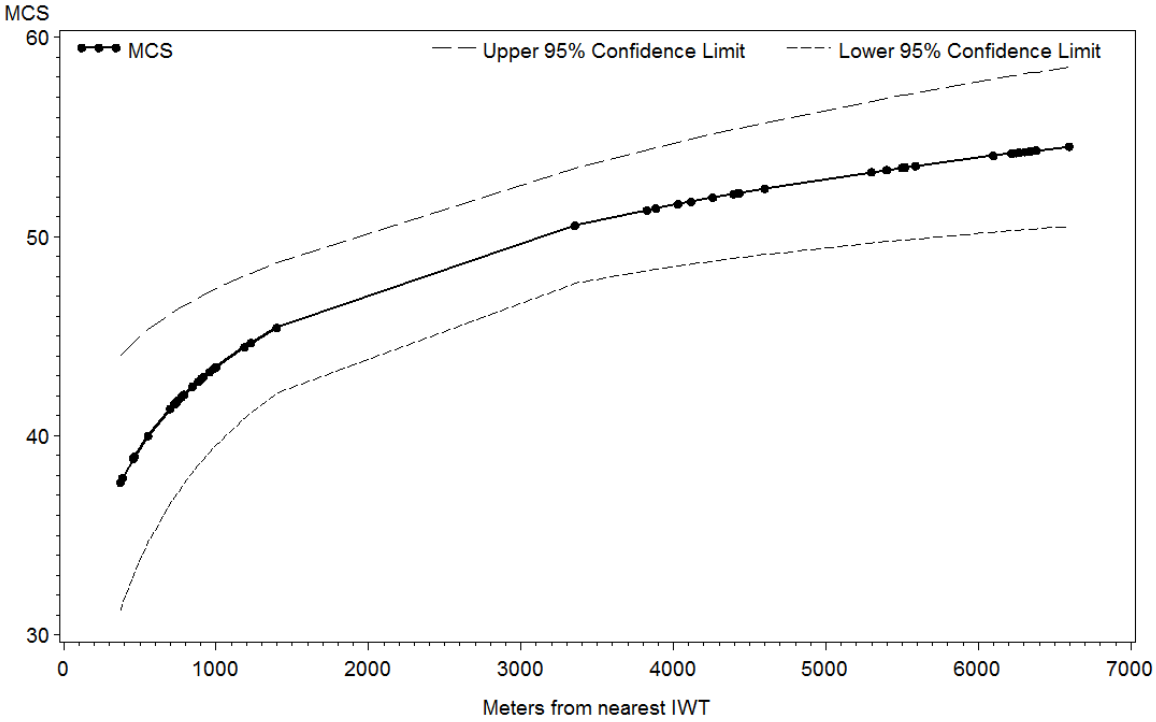

Figure 3: Modeled SF36 Mental Component Score (MCS) vs Distance (mean and 95 % confidence limits), p-value=0.0014

DISCUSSION

This study, which is the first controlled study of the effects of IWT noise on sleep and health, shows that those living within 1.4 km of IWT have suffered sleep disruption which is sufficiently severe as to affect their daytime functioning and mental health. Both the ESS and PSQI are averaged measures, i.e. they ask the subject to assess their daytime sleepiness and sleep quality respectively, over a period of several weeks leading up to the present. For the ESS to increase, sleep must have been shortened or fragmented to a sufficient degree on sufficient nights for normal compensatory mechanisms to have been overcome. The effects of sleep loss and daytime sleepiness on cognitive function, accident rate and mental health are well established (WHO 2009) and it must be concluded that at least some of the residents living near the Vinalhaven and Mars Hill IWT installations have suffered serious harm to their sleep and health.

The significant relationship between the symptoms and distance from the IWTs, the subjects' report that their symptoms followed the start of IWT operations, the congruence of the symptoms reported here with previous research and reports and the clear mechanism is strong evidence that IWT noise is the cause of the observed effects.

IWT noise has an impulsive character and is several times more annoying than other sources of noise for the same sound pressure level (Pedersen & Persson Waye 2004). It can prevent the onset of sleep and the return to sleep after a spontaneous or induced awakening. Road, rail and aircraft noise causes arousals, brief lightening of sleep which are not recalled. While not proven, it is highly likely that IWT noise will cause arousals which may prove to be the major mechanism for sleep disruption. It is possible that the low frequency and infrasound components of IWT noise might contribute to the sleep disruption and health effects by other mechanisms but this remains to be determined and further research is needed.

Attitudes to IWT and visual impact have been shown to be factors in annoyance to IWT noise (Pedersen et al. 2009) but have not been demonstrated for sleep disturbance. Most respondents in the present study welcomed the IWT installations as offering economic benefits. The visual impact of IWT decreases with distance, as does the noise impact making separation of these factors impossible.

We conclude that IWT noise at these two sites disrupts the sleep and adversely affects the health of those living nearby. The current ordinances determining setback are inadequate to protect the residents and setbacks of less than 1.5 km must be regarded as unsafe. Further research is needed to determine a safe setback distance and to investigate the mechanisms of causation.

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