Environmental Research 148 (2016) 401–410

Contents lists available at ScienceDirect

Environmental Research

journal homepage: www.elsevier.com/locate/envres

The impact of psychological factors on self-reported sleep disturbance among people living in the vicinity of wind turbines

Leila. Jalali [a,*], Mohammad-Reza. Nezhad-Ahmadi [b], Mahmood Gohari [a], Philip Bigelow [a], Stephen McColl [a]

[a] University of Waterloo, School of Public Health and Health Systems, Waterloo, Ontario, Canada
[b] University of Waterloo, Electrical and Computer Engineering, Waterloo, Ontario, Canada

ARTICLE INFO

Article history:
Received 22 January 2016
Received in revised form
25 March 2016
Accepted 18 April 2016
Available online 29 April 2016

Keywords:
Wind turbine noise
Sleep disturbance
Psychological factor
Cohort study

ABSTRACT

Canada's wind energy capacity has grown from approximately 137 MW (MW) in 2000 to over 9700 MW in 2014, and this progressive development has made Canada the fifth-largest market in the world for the installation of new wind turbines (WTs). Although wind energy is now one of the fastest growing sources of power in Canada and many other countries, the growth in both number and size of WTs has raised questions regarding potential health impacts on individuals who live close to such turbines.

This study is the first published research using a prospective cohort design, with noise and sleep measurements obtained before and after installation of WTs to investigate effect of such turbines on self-reported sleep disturbances of nearby residents. Subjective assessment of sleep disturbance was conducted in Ontario, Canada through standard sleep and sleepiness scales, including the Pittsburgh Sleep Quality Index (PSQI), Insomnia Severity Index (ISI), and Epworth daytime Sleepiness Scale (ESS). Both audible and infra-sound noises were also measured inside the bedroom. Descriptive and comparison analyses were performed to investigate the effect of WT exposure on sleep data.

Results of the analysis show that participants reported poorer sleep quality if they had a negative attitude to WTs, if they had concerns related to property devaluation, and if they could see turbines from their properties. This study provides evidence for the role of individual differences and psychological factors in reports of sleep disturbance by people living in the vicinity of WTs.

1. Introduction

Low operating cost and extensive availability make wind one of the most advantageous and effective alternatives to fossil energy. Like many countries, Canada has set a policy goal to extensively increase use of wind energy as a response to the threat of climate change, vowing to produce 20% or more of its electricity from wind by 2025 ("Canadian Wind Energy Association," 2016). Wind energy, as a low-carbon power source, is intended to have positive impacts on the health of the population at large. However, as wind farms are being sited closer to residential area to reduce transmission losses and costs, health-related effects of exposure to wind turbine (WT) noise have attracted much public attention. As the number of exposed people is growing, public resistance to such visible sound sources is becoming the main obstacle to wind energy development (van den Berg et al., 2008).

Sleep disturbance is relatively common in the general population and has multiple causes, including medical conditions, stress, and external stimuli such as noise. Human beings perceive, evaluate, and react to environmental noises during sleep (Dang-Vu et al., 2010). With respect to WT noise, the key issue is whether the noise is loud enough to disrupt sleep. Published results from previous cross-sectional studies have been inconsistent in terms of possible effects of WT noise on sleep. On one hand, those studies that used an objective method to measure exposure found no, or only a week association between noise and sleep disorders. As an example, a large Canadian study that provided the most-comprehensive assessment of the association between exposure to WT noise and sleep found no sleep-noise association for a noise level under 46 dB(A) (Michaud et al., 2015). A few other cross-sectional studies with reasonable sample size did find only a weak dose response relationship between noise and self-reported sleep (at levels between 40 and 45 dB(A)) or found that annoyance ratings were more strongly associated with self-reported sleep disturbance than noise (Bakker et al., 2012; McCunney and Mundt, 2014; Pawlaczyk-Łuszczyńska et al., 2014; Pedersen and Persson Waye, 2004a, 2004b). This findings are consistent with WHO's conclusion that significant sleep disturbance from environmental

* Corresponding author.
E-mail address: l2jalali@uwaterloo.ca (Leila. Jalali).

http://dx.doi.org/10.1016/j.envres.2016.04.020
0013-9351/

noise begins to occur at noise levels greater than 45 dB(A) (Fritschi et al., 2011).

On the other hand, those studies that used "distance to nearest WT" as an exposure measure, almost all agreed that self-reported sleep disturbances were more frequent in subjects living closer to WTs than in subjects living further away (Krogh et al., 2011; Kuwano et al., 2013; Nissenbaum et al., 2012; Paller, 2014; Shepherd et al., 2011a).

Based on the current findings, it is not possible to conclude that self-reported sleep disturbance is caused directly by WT noise or whether other factors have played a role as well. Most critically, due to the cross-sectional design of previous studies, there is a complete lack of prospective longitudinal designs and temporal sequence of exposure–outcome relationships cannot be demonstrated.

This epidemiological study was undertaken to explore the possibility of sleep disturbance and the role of psychological factors in self-reported sleep disruption in people living within close proximity of WTs, in a pre- and post-study design. We hypothesized that non-noise variables, such as attitude, visual cues and concern about property devaluation play an important role and likely contribute to observations that people living near WTs report higher levels of sleep disturbance.

2. Methods

2.1. General study design and questionnaire development

This research employed a prospective cohort design and included a sleep questionnaire, comprised of validated instruments relating to sleep disturbance, daytime sleepiness and insomnia. In order to measure participants' sleep quality, the Pittsburgh Sleep Quality Index (PSQI) was used. The PSQI is a 19-item self-rated sleep questionnaire evaluating sleep quality and disturbances over a previous month; these items are grouped into seven domains: subjective sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbances, use of sleep medication, and daytime dysfunction. Each component of the PSQI obtains scores ranging from 0 (no impairment) to 3 (maximum impairment). A total score, ranging from 0 to 21, is obtained by adding up the 7 component scores; higher scores indicate worse sleep quality, and a score >5 suggests poor sleep quality (Buysse et al., 1989).

Subjective daytime sleepiness was evaluated by means of the Epworth Sleepiness Scale (ESS). The ESS is a questionnaire consisting of eight self-rated items, each scored from 0 to 3, asking participants to rate their chance of dozing off during eight different common situations of daily living. It provides a score between 0 (least sleepy) and 24 (most sleepy) (Johns, 1991). No specific time frame is specified. According to the University of Maryland Medical Center, (2016) an ESS score >10 is considered to indicate significant daytime sleepiness.

The nature, severity, and impact of insomnia were assessed by the Insomnia Severity Index (ISI) (Morin and Barlow, 1993), which is a 7-item self-report questionnaire assessing the severity of sleep onset, sleep maintenance, early morning awakening problems, sleep dissatisfaction, interference with sleep, difficulties with daytime functioning, noticeability of sleep problems by others, and distress caused by sleep difficulties in the previous month. A 5-point Likert scale is used to rate each item (0=no problem; 4=very severe problem), yielding a total score ranging from 0 to 28. The total score is interpreted as follows: absence of insomnia $(0-7)$; sub-threshold insomnia $(8-14)$; moderate insomnia $(15-21)$; and severe insomnia $(22-28)$.

Noise sensitivity and attitude to WTs were also measured in T2 on a 5-point scales with 3 representing a neutral attitude and slightly noise sensitive, respectively (Items are: not sensitive, hardly sensitive, slightly sensitive, rather sensitive, very sensitive and very positive, positive, neither positive nor negative, negative, very negative, respectively). Noise sensitivity and attitude were also dichotomised into "not sensitive" and "sensitive" (1–3 vs. 4–5), and attitude into "not negative" and "negative" (1–3 vs. 4–5). Participants were also asked if they benefited from WTs and/or owned land on which a WT facility was built.

2.2. Noise exposure assessment

At two locations, that varied each night, indoor noise was measured for a total of 16 nights before and 16 nights after operation of the turbines. In total, 64 sets of data were collected. A noise-measurement system was placed in participants' bedrooms (if they agreed) for the duration of their sleep. The system was programmed to turn on and off automatically at the start and end of each period. The indoor microphone was fitted with a windscreen and mounted on a microphone stand in the bedroom at a location close to the participant's head, at the same height as the sleeper and one meter horizontally from his or her head. A Soundbook analyzer (MK1) (Sinus/Messtechik, Germany) was used with a G. R. A. S 40AZ low frequency microphone. The whole system is capable of measuring noise in the 0.5 Hz to 20,000 Hz frequency range. It was calibrated before and after each recording using a known frequency (250 Hz) and SPL (114 dB) source. The results of the sound measurements and recordings were transferred from the Soundbook to a personal computer. Further processing and calculations were performed using the software package Samurai 2.6 (Soundbook.de 2009).

For the purposes of this paper, noise measurement has been analyzed for only one-hour (1 h)/night, and this 1 h were chosen from a period when inside spikes (e.g., from coughing, dogs barking) were minimal. A-weighted and Z-weighted parameters (Laeq-1H, Zaeq-1H) were then extracted from the measured noise data. Additional noise parameters such as L_{ZFmax}, $L_{ZFmin,}$ L_{AFmax}, L_{AFmin}, L_{ZFmax}-L_{ZFmin}, L_{AFmax}-L_{AFmin} over 10 min per night were also extracted. Wind speed data were taken (at 10 m height) from the closest weather station to the WTs.

2.3. Participant selection

This study was carried out in a rural area with flat agricultural fields in southern Ontario, Canada. Operation of five Vestas V100–1.8 MW turbines, with hub heights of 90 m and rotor diameters of 100 m, was started in June 2014. Pre-Construction and environmental studies were completed by the wind company between April to July 2012. The first round of data collection was conducted post turbine erection but pre operation to avoid construction noise effects on sleep quality (March 2014). The second round of data collection occurred after the turbines became operational and it happened in the same time of year (March 2015) to minimize seasonal and temperature effects. The coordinates of both local residential properties and WTs were produced using ArcGIS Desktop Version 10.3.1 (Esri Inc, Redlands, CA). The distance between a participant's residence and the nearest WT was calculated using a Global Positioning System (GPS). All residents living within 2000 m of the turbines were identified and residential address centroids were generated from Municipal Property Assessment Corporation (MPAC) data.

For all 195 eligible households (businesses and unoccupied addresses were excluded) within 2000 m of the WTs, letters of advance notice including study details and the researchers' contact information were placed in mailboxes two weeks prior to survey distribution. For homes without mailboxes, advance notices were delivered to the door. Within two weeks of advance-notice letter delivery, two researchers visited each eligible household. During door-to-door recruitment, they provided information about the study, including potential risks and participant responsibilities. For those who agreed to participate, a study package, containing the survey instruments, information letters, and prepaid return mail envelopes, was provided. The study package was left in the mailbox if researchers had visited a house three times without meeting the residents. Reminder postcards or phone calls (participant's choice) were made three to four weeks after the surveys were distributed. Those who were not interested in participating were invited to fill out a short questionnaire that asked only a few questions about their age, overall quality of sleep, and whether they supported community-owned renewable energy. A certified sleep technologist/ sleep researcher (LJ) supervised the distribution and encouraged participation.

This study received ethics clearance from University of Waterloo Human Research Ethics Committee.

2.4. Statistical analysis

Pittsburgh Sleep Quality Index scores were calculated using the scoring instructions available from the University of Pittsburgh Sleep Medicine Institute (Buysse et al., 1989). Independent variables assessed in this study included the following: distance to WT (<1000 m, >1000 m), age (continuous and categorical: middle age: 30–55 and older adult >55), gender (male, female), attitudes to WT (negative, not negative), concerns about property values (concerned, not concerned) and turbine visibility (visible, not visible). The dependent variables that were assessed included the following: ESS, PSQI and ISI (continuous variables). Due to the small sample size, distances to WTs were dichotomised only to above and below 1000 m (categorizing to higher number of groups would have resulted in only a small number of participants in each category). The distributions of continuous variables are presented as mean $\pm$ SD and frequency and percentage of categorical variables are also reported. Normality assumption for sleep measures were examined using Shapiro-Wilks tests. Non-parametric analyses were performed for those variables (PSQI-T2, ESS-T1, ESS-T2, ISI-T1, and ISI-T2) that were not normally distributed. Wilcoxon signed rank test used for comparing mean distribution of two continuous and related samples, and Mann-Whitney test was used to compare mean differences of measures in two independent groups.

Independent sample *t*-test and chi square tests were used to compare the mean distribution of continues and categorical variables for two non-related samples (participants and non-participants/ participants and “lost to follow up” groups), respectively.

Spearman's rank correlation coefficients were calculated to determine the strength of the relationship between the noise-exposure parameters and distance to the nearest turbines. The significant level was considered as a p-value of <0.05. All analyses were performed using SPSS, Version 22 for the Windows 8 operating system (IBM Corp. 2013).

3. Results

3.1. Sleep survey

Table 1 shows the demographic characteristics of the participants. Of 195 identified residential households within 2000 m of five 1.8 MW turbine farms, 50 questionnaires in T1 and 37 questionnaires in T2 were returned, for a response rate of about 30%.

The mean age of participants was 54.25 years, and 43.2% were male. The majority (91.9%) lived in privately owned detached houses in the countryside and the landscape was rather flat and mainly agricultural. Of the participants, 45.9% had a negative attitude to WTs, 51.3% had positive or neutral attitude to turbines, and 67.6% were concerned about the value of their properties.

Table 1
Demographic Characteristics of Participants of Wind Turbine and Sleep Study, Ontario, Canada, 2015.

Variable		**N**	**%**
Gender	Male	16	43.2
	Female	21	56.8
Marital status	Married/ common-law	34	91.9
	Separated or widow	3	8.1
Occupation	Full time employment	18	48.6
	Retired	12	32.4
	Part-time/self-employment	7	18.9
Education	Post-Graduate college/ university	31	83.7
	High school diploma/Less than secondary	4	10.81
	Not answered	2	5.49
Own their home	Yes	34	91.9
	Rented or others	3	8.1
Distance to nearest turbine	<1000 m	22	59.5
	>1000 m	15	40.5
Turbine visibility	Yes	34	91.9
	No	3	8.1
Bedroom facing turbine	Yes	22	59.5
	No	15	40.5
Bedroom location	First floor	23	62.2
	Second floor	14	37.8
Double glass window	Yes	34	91.9
	Not answered	3	8.1
Noise sensitivity	Not or hardly sensitive	20	54
	Slightly sensitive	7	18.9
	Rather or very sensitive	10	27
Concerns for property devaluation	Yes	25	67.6
	No	12	32.4
General attitude toward wind turbines	Very negative	9	24.3
	Negative	8	21.6
	Neither negative or positive	7	18.9
	Positive	8	21.6
	Very positive	4	10.8
	Not answered	1	2.7
Window status at bedtime	Usually open	18	48.6
	Closed	18	48.6
	Not answered	1	2.7
Age (mean, range)		54.25(33,78)	

Of non-participants 83% filled out the short questionnaire. There were no significant differences between the non-participants and participants by age ($p=0.130$) and sex ($p=0.440$). A significantly greater number of participants (59.5%) lived within 1000 m of the nearest turbines compared to 31.7% of non-participants ($p=0.020$). Of the participants in T1, 91.9% rated their sleep as good or very good compared to 79.6% of non-participants ($p=0.163$).

There also were no significant difference between the participants and “lost to follow up” group by age ($p=0.251$, sex ($p=0.948$), distance (p=0.676), ESS means (p=0.376), PSQI means ($p=0.636$) and ISI means ($p=0.758$).

The mean values for each of the dependent variables in T1 and T2 and the p values are shown in Table 2. The mean of the PSQI, ESS and ISS scores significantly increased by 2.11(SD=4.34), 2.45 (SD=4.71) and 3.32 (SD=6.24) units after exposure, respectively.

To uncover the reason for decreasing sleep quality, participants were questioned about ten different factors that generally interrupt sleep. Only 13.9% (5 people) identified WTs as the sound source of sleep disturbance (from1–2 times a week to less than once a week), and other factors such as aircraft, wind, and thunderstorms were more often identified as causing sleep disturbance than WTs.

The mean differences of dependent variables (T2-T1) compared between two groups of independent variables such as distance from the nearest WT, sex, age, concern about property values,

Table 2
Mean Scores of Sleep Outcomes before and after Long-term Exposure (N=37), in Wind Turbine Sleep Study, Ontario, Canada.

Variable	Time1 N=37 Mean (SD)	Time2 N=37 Mean (SD)	P[a] (T1,T3) N=37
Pittsburgh Sleep Quality Index	4.08 (2.13)	6.19 (3.89)	**0.006**
Epworth Sleepiness Scale	4.68(3.22)	7.13(5.25)	**0.002**
Insomnia Severity Index	3.11(3.58)	6.43(6.66)	**0.005**

[a] Wilcoxon signed rank test was performed for analysis.

attitude to WTs, noise sensitivity, and window and bedroom situation. The results are shown in Table 3. Changes in PSQI scores over time were strongly associated with negative attitudes to WTs, turbine visibility, and being concerned about property values. Changes of ISI scores also strongly related to property devaluation concerns and negative attitude to WTs. As demonstrated in Fig. 1, PSQI and ISI values stayed constant over the time for people who did not have anxiety about the value of their properties, and also for those with positive or neutral attitudes to WTs.

The number of participants, who benefited economically from the turbines, was too small for meaningful statistical analysis.

3.2. Noise

The average A-weighted noises measured in T1 and T2 observation were not significantly different, with a mean of 31.52 dB (A) (SD=5.16) in T1 and 31.23 dB (A) (SD=4.91) in T2 (p=0.740). The average Z-weighted noises measured in T1 and T2 observation were also not significantly different, with a mean of 59.93 dB (Z) (SD=27.33) in T1 and 57.44 dB (Z) (SD=28.49) in T2 (p=0.090). The noise information for three participating receptors is summarized in Table 4.

Mean and p-value for fast averaging noise parameters for L_{ZFmax}, L_{ZFmin}, L_{AFmax}, L_{AFmin}, L_{ZFmax}-L_{ZFmin}, L_{AFmax}-L_{AFmin} over 10 min per night at Time1 and Time2 are shown in Table5. Noise data for these 6 parameters were not significantly different between Time1 and Time 2.

Fig. 2(a) and (b) identify the relationship between distance from the closest WT and noise levels (Laeq, Lzeq). The results of Spearman's correlation indicate no significant correlation between distance and inside noise in T2 (Laeq-1H: Spearman's r=−0.353, p=0.180, Lzeq-1H: Spearman's r=−0.080, p=0.769).

Associations between noise exposure and sleep parameters were not calculated, as only a small number of participants agreed to noise measurement in their bedrooms.

4. Discussion

This study is the first to use a repeated noise and sleep measurement before and after WT operation to investigate the impacts of WT presence on self-reported sleep quality with considering psychological factors such as visibility of and attitude toward WTs and concern related to property devaluation. Hosting a new wind farm in the community was found to be associated with increased reports of poor sleep quality, daytime sleepiness, and rates of insomnia as evidenced by significantly greater means for PSQI, ESS and ISI scores. Changes of PSQI and ISI values were strongly associated with negative attitudes to WTs and concerns about property values. Changes of PSQI scores were also associated with WT visibility, with those able to see turbines from their residence experienced worse sleep than others.

Results of this study are consistent with the majority of previous epidemiological studies showing that people's sleep is disturbed by exposure to WTs (Bakker et al., 2012; Kuwano et al., 2013; Nissenbaum et al., 2012; Onakpoya et al., 2015; Pawlaczyk-Łuszczyńska et al., 2014; Pedersen and Persson Waye, 2004a, 2004b; Shepherd et al., 2011a, 2011b. However, contrary to expectation, changes in the mean values of sleep variables were not associated with distance to WTs but instead strongly associated

Table 3
Sleep outcomes changes over time versus gender, age, distance, turbine visibility, bedroom and windows status, concern about property values, attitude to wind turbines and noise sensitivity, in wind turbine sleep study, Ontario, Canada.

Variables	Pittsburgh Sleep Quality Index			Epworth Sleepiness Scale			Insomnia Severity Index		
	Time1 Mean (SD)	**Time2 Mean (SD)**	**P[*]**	**Time1 Mean (SD)**	**Time2 Mean (SD)**	**P[*]**	**Time1 Mean (SD)**	**Time2 Mean (SD)**	**P[*]**
Male	3.44(2.19)	5.69(3.70)	0.453	4.81(3.25)	5.80(3.53)	0.186	1.81(2.68)	5.33(4.70)	0.256
Female	4.57(1.99)	5.95(2.99)		4.57(3.28)	6.90(5.05)		4.10(3.92)	5.50(5.77)	
Middle age (30–55)	4.15(2.18)	5.60(3.41)	0.602	4.45(2.95)	5.47(3.42)	0.164	1.90(1.91)	4.42(4.36)	0.845
Older adult (>55)	3.87(2.12)	6.07(3.30)		5.06(3.68)	7.67(5.46)		4.69(4.64)	6.66(6.36)	
Distance <1000 m	4.09(2.33)	6.52(3.52)	0.212	5.09(3.04)	7.15(3.99)	0.744	3.64(4.10)	6.42(5.72)	0.511
>1000 m	4.07(1.87)	4.87(2.75)		4.07(3.49)	5.47(4.94)		2.33(2.61)	4.07(4.40)	
Turbine visible	4.03(2.10)	6.18(3.20)	**0.030**	4.88(3.26)	6.62(4.48)	0.817	3.18(3.70)	5.90(5.26)	0.105
Turbine not-visible	4.64(2.89)	2.00(1.00)		2.33(1.53)	4.33(4.04)		2.33(2.08)	0.3(0.57)	
Bedroom toward turbine : Yes	4.05(1.98)	5.81(3.35)	0.988	4.50(2.87)	6.95(4.66)	0.083	2.91(3.66)	5.57(5.99)	0.479
No	4.13(2.39)	5.87(3.29)		4.93(3.77)	5.64(4.10)		3.40(3.58)	5.21(4.13)	
Bedroom's floor: First	4.13(2.20)	5.77(2.67)	0.794	5.61(3.62)	7.14(4.81)	0.561	3.30(3.28)	5.27(4.25)	0.716
Second	4.00(2.07)	5.92(4.18)		3.14(1.56)	5.23(3.56)		2.79(4.15)	5.69(6.83)	
Windows : Close at bedtime	3.83(2.41)	6.06(3.70)	0.515	5.06(3.24)	6.56(3.03)	0.302	2.78(3.56)	5.44(4.76)	0.685
Open at bedtime	4.44(1.82)	5.78(2.96)		4.39(3.33)	6.61(5.42)		3.50(3.77)	5.61(5.89)	
Double glass window: Yes	4.15(2.18)	5.91(3.34)	0.781	4.59(3.06)	6.24(3.97)	0.853	2.97(3.66)	5.60(5.37)	0.321
No	3.33(1.53)	4.50(2.12)		5.67(5.50)	9.50(12.02)		4.67(2.51)	2.50(0.71)	
Concern for property value: Yes	3.96(1.94)	7.12(3.15)	**0.001**	4.00(2.50)	6.48(4.00)	0.059	3.40(3.76)	7.39(5.48)	**0.003**
No	4.33(2.53)	3.25(1.60)		6.08(4.14)	6.33(5.35)		2.50(3.26)	1.66(1.43)	
Negative Attitude to turbine: Yes	3.71(1.99)	7.31(3.52)	**0.002**	3.41(2.15)	5.80(3.61)	0.241	3.47(4.47)	8.67(5.98)	**0.003**
No	4.53(2.22)	4.42(2.45)		5.95(3.61)	6.89(5.14)		2.95(2.69)	2.84(2.94)	
Not-noise sensitive	4.44(2.11)	5.48(3.40)	0.053	5.48(3.31)	7.00(4.75)	0.778	3.11(3.74)	5.03(5.64)	
Rather or very sensitive	3.10(1.91)	6.89(2.80)		2.5(1.65)	4.50(2.44)		3.10(3.31)	6.75(3.73)	0.323

[*] p value compares the mean difference between T2 and T1 for each two categories and Mann Whitney U test was used to obtain each p-value

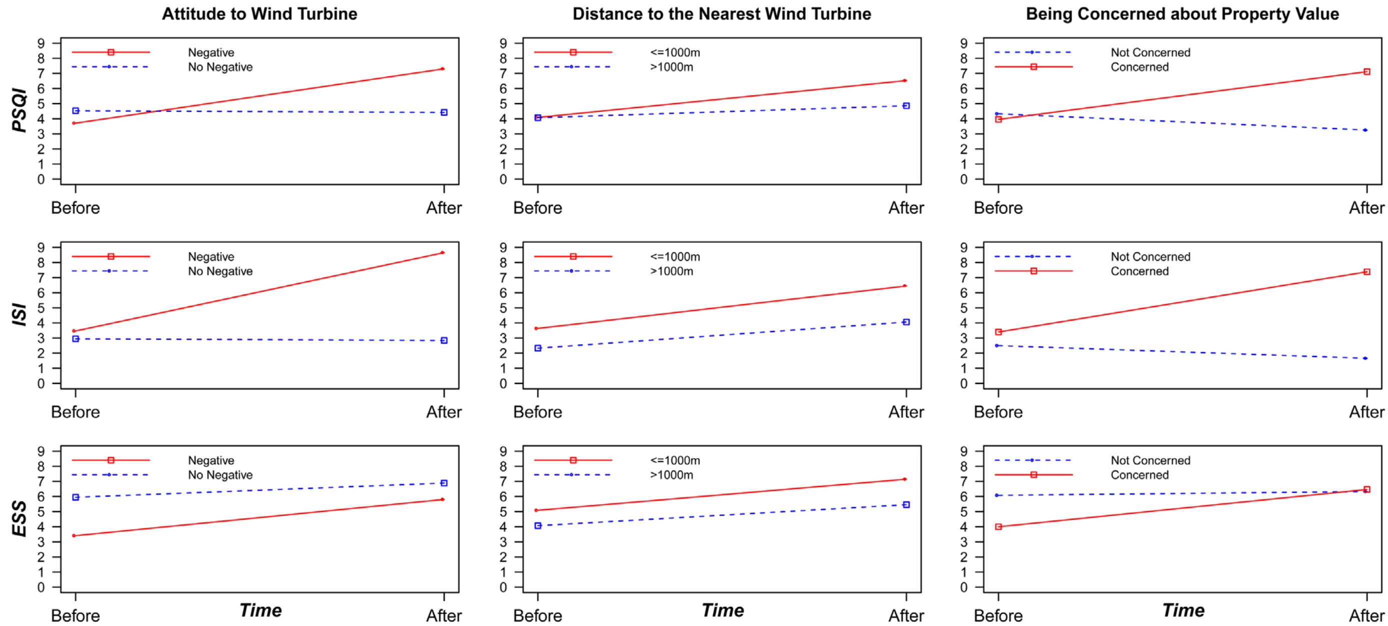

Fig. 1. : Variation of Pittsburgh Sleep Quality Index (PSQI), Insomnia Severity Index (ISI) and Epworth Sleepiness Scale (ESS) over time versus distance, attitude to turbines, and concern about property value.

Table 4
A-weighted and Z-weighted Sound Levels Measured in 3 Participating Receptors (inside the bedrooms).

	Time 1 Wind speed m/s	Laeq	lzeq	Time2 Wind speed m/s	Laeq	Lzeq
Participating receptor1/ Night 1	4.39	34.7	60.9	3.06	37.1	58.8
Participating receptor1/ Night 2	3.78	25.7	56.6	4.36	30.5	66.3
Participating receptor2/ Night 1	4.39	34.1	58.9	3.06	37.1	58.8
Participating receptor2/ Night 2	3.78	34.7	55.6	4.36	37.1	66.8
Participating receptor3/ Night1	2.72	26.9	55.5	2.36	32.3	59.4
Participating receptor3/ Night2	6.06	27.5	65.3	1.86	34.6	57.2

Table 5
Mean and p-value for Fast Averaging Noise Parameters for Time1 and Time2.

Noise Parameters	Mean $\pm$ SD /Time1	Mean $\pm$ SD /Time2	*P*-value
LZFmax	70.67 ± 7.15	68.25 ± 6.45	0.202
LZFmin	45.58 ± 4.93	43.66 ± 3.89	0.090
LAFmax	46.19 ± 7.53	46.55 ± 6.81	0.805
LAFmin	20.25 ± 4.67	21.69 ± 4.28	0.127
LZFmax-LZFmin	25.09 ± 4.82	24.59 ± 4.78	0.680
LAFmax-LAFmin	25.94 ± 8.48	24.86 ± 6.42	0.489

with subjective factors such as attitude to WTs, visual impact, and concern about property values.

Significant amounts of the research in the field of WT noise and health effects support a relationship between subjective factors and health-related symptoms from annoyance to sleep disorders, stress and psychological disorders (Bakker et al., 2012; Pawlaczyk-Łuszczyńska et al., 2014; Pedersen and Persson Waye, 2007, 2004a; Wolsink et al., 1993). Pedersen and Persson Waye, (2004a, 2007) indicated that attitude toward the visual effect of WTs is an important contributor to any annoyance associated with WT noise and it increases the chance of perceiving noise and reporting symptoms such as poor sleep quality, negative emotions and self-reported stress. Taylor et al., (2013) also confirmed such results and stated that individual differences play a key role in the link between perceived noise and WT-related symptom-reporting. They claimed that those who had a more-negative attitude to WTs perceived more noise from turbines and reported more symptoms.

A possible mechanism for the sleep effects observed in this study may be attributed to the indirect effects of concerns and attitudinal cues. Most participants (77.8% in T2) believed that WTs did not interrupt their sleep in previous month, thus confirming the low level of noise in the community (8.4% also chose the "Not Applicable" or "Don't Know" options). The indoor noise measurement in this study also confirmed low levels of noise in bedrooms and also no significant differences in noise level between T1 and T2. In addition, general outdoor noise levels in the area, obtained from a conference paper by Ramakrishnan and Seharwat (2015), were reported to range from 40 to 45 dB(A) before and 38–42 dB(A) after turbine operation. Increases in perceptions of poor sleep at a time when the average noise level had not changed significantly demonstrate that other factors may be at play in an individual's perceived of sleep quality. Concern about new environmental changes, especially those associated with non-perceptible exposures such as low frequency noise, appear to act as a trigger for such reports of ill health (Petrie et al., 2001; Taylor et al., 2013). Several studies have observed that people who are concerned about an environmental risk are more likely to report health symptoms (Claeson et al., 2013; Mcmahan and Meyer, 1995; Moffatt et al., 2000; Petrie and Broadbent, 2005). Association between psychological factors and sleep has been reported in a study by Magari et al., (2014) on the impacts of WT noise. They found a correlation between participant concerns regarding health effects from WTs and their having experienced sleep disturbances and stress.

Ruminating about daily events is one of the common sources of sleep disturbance. Any new WT development is likely to be a source of concern, leading local people to ruminate about it at night. Rumination, like worry, functions as a source of pre-sleep cognitive arousal and interferes with sleep quality, perhaps causing sleep-related difficulties (Guastella and Moulds, 2007).

Concern about property values is commonly cited as an issue in communities in the vicinity of WTs. In the current study, 67.6% of

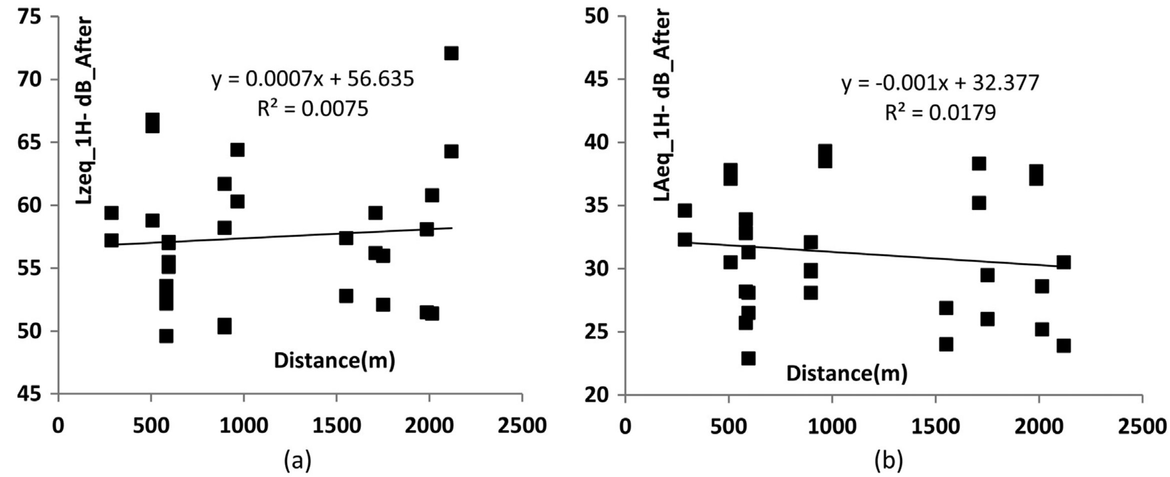

Fig. 2. a: Time 2 (after exposure) Z-weighted equivalent noise versus distance from the closest wind turbine for 1 h measurement. (b): Time 2 (after exposure) A-weighted equivalent noise versus distance from the closest wind turbine for 1 h measurement.

participants were concerned about the value of their property, and PSQI and ISI values stayed constant over the time for people who did not have anxiety about the value of their properties.

WT as a new element of the landscape can be potential source of stress and fear (Pedersen, 2011). Stress is frequently seen as a significant contributor to disease, and clinical evidence supports the effects of stress on immune and cardiovascular systems (Brotman, et al. 2007;Segerstrom and Miller, 2004). The Ontario Government needs to develop new policies to support communities that host wind facilities and address their concerns and fears. Ellenbogen et al., (2012) suggested strategies engaging the public in wind energy projects, including public education related to renewable energy, incentives for community-owned wind developments, compensation to those experiencing documented loss of property values, and comprehensive setback guidelines.

To the best of authors' knowledge, this is the first study of WT-related sleep disturbances that collected indoor sound pressure levels before and after WT operation, and it is one of the first studies in this field that has ever measured inside bedroom noise. Most of the previous studies used distance as exposure measurement or modeled the noise for a given geographical area. Sleep was also measured repeatedly, by using multiple standard sleep questionnaires before and after exposure. Beaudreau et al., (2012) stated that the PSQI and ESS questionnaires are internally consistent, and they are valid measures of self-reported sleep problems. Considering these strengths, we acknowledge that due to the field study design, there was a lack of control, both with regards to the exposure levels and wind speed, and with other possible sources of variation that might affect results such as impulsive and tonality section of the noise. Moreover, several other factors impact measurement and exposure to WT noise including characteristics of the participants home, weather conditions, local flora and topography, and the number of and layout of the turbines. Larger wind farms tend to generate more noise than smaller ones, as several WTs in the same vicinity can lead to increased pulse sounds, with increased sound pressure levels of 5 dB (van den Berg 2004). It is also common for old turbines to operate at a fixed speed, or perhaps at one or two fixed speeds, depending on the wind speed. However, new turbines are fully variable in blade rotational speed and so are able to operate at the most efficient rotational speed across a wide range of wind speeds. The result of this technological improvement is that noise emissions are lower at low speeds of rotation in light winds.

This study has also several other important limitations. Recall bias for symptoms might have resulted in people who were worried about possible adverse health effects remembering more symptoms from the recent past than people who were not worried, even if the actual level of symptoms was the same in the two groups. Non-response bias may have affected results because residents closer to turbines were more interested in participating in the study than those further away. The presence of this bias may have led to overestimation of the association between exposure and outcome because residents who lived further away from turbines and expected to have fewer health effects were less interested in participating.

Although we used various methods to increase participation, including phone call/postcard reminders, offering an incentive for participating in the survey, door to door recruitment instead of mail, and pre-notifying residents about the study, due to other factors such as socio-political topic the response rate was low and this means that this study might have failed to capture the self-reported sleep disorder of many people within the study population, resulting in poor sample representativeness.

Correlation between the exposure to the WT noise and the health assessment is complex and further synchronous noise and physiological signal recording and analysis are required to understand interaction between WT noise and physiological parameters. Future studies should involve representative samples of the population including vulnerable groups such as children, chronically ill subjects, elderly, and habitually short sleepers, and also evaluate sleep quality in residents living adjacent to older WTs.

5. Conclusion

This novel work has highlighted the role of psychological factors and how they may lead to the development of health complaints in those living near wind farms. It appears that self-reported sleep reported of participants may be associated to the indirect effects of visual and attitudinal cue and concern about property devaluation rather than distance to the nearest WTs or noise as itself. However, firm conclusions are not possible due to the discussed limitations.

Competing financial interests

The authors declare no conflicts of interest.

Founding resources

This research is supported by Ontario Research Chair in Renewable Energy Technologies and Health.

Ethic clearance (ORE #: 19445)

This study has been reviewed and received ethics clearance from the University of Waterloo Human Research Ethics Committee.

Acknowledgements

The authors acknowledge the support and advice they received from the Ontario Research Chair in Renewable Energy Technologies and Health and Niagara Region Public Health. A special thanks to Ryan Waterhouse for his help on GIS analysis. We are especially grateful to the volunteers who participated in this study.

Appendix 1

Sleep survey

The following questions relate to your typical sleep habits during the past month. Your answers should indicate the most accurate reply for the majority of days and nights in the past month.

During the past month…	
1. What time have you usually gone to bed? (please also circle a.m. or p.m.)	___________ a.m./p.m.
2. How long has it taken you to fall asleep each night? (Once you have decided to go to sleep)	___________ minutes
3. What time have you usually woken up in the morning? (Please also circle a.m. or p.m.)	___________ a.m./p.m.
4. How many hours of actual sleep do you get at night? (This may be different than the number of hours you spend in bed)	___________ Hours

5. During the past month, how would you rate your sleep quality overall?

□ Very Good □ Fairly Good □ Fairly Bad □ Very Bad

During the past month, how often have you had trouble sleeping because you…

	Not in the past month	Less than once a week	1-2 times a week	3+times a week
6. Cannot get to sleep within 30 min?	1	2	3	4
7. Wake up in the middle of the night or early morning?	1	2	3	4
8. Have to get up to use the bathroom?	1	2	3	4
9. Cannot breathe comfortably?	1	2	3	4
10. Cough or snore loudly?	1	2	3	4
11. Feel too cold	1	2	3	4
12. Feel too hot?	1	2	3	4
13. Have bad dreams?	1	2	3	4
14. Have pain?	1	2	3	4

15. Other (please specify): ______________________________

During the past month…

	Not in the past month	Less than once a week	1-2 times a week	3+times a week
16. How often have you taken medicine (prescribed or "over the counter") to help you sleep?	1	2	3	4
17. How often have you had trouble staying awake while driving, eating meals, or engaging in social activity?	1	2	3	4
18. How much of a problem has it been for you to keep up enthusiasm to get things done?	1	2	3	4

The following questions are about what generally interrupts your sleep.

During the past month, how often was your sleep interrupted by…	Not in the past month	Less than once a week	1-2 times a week	3+times a week	I don't know/ NA
19. Noises from inside your home?	1	2	3	4	□
20. Road traffic?	1	2	3	4	□
21. Aircraft and air traffic?	1	2	3	4	□
22. Rail traffic?	1	2	3	4	□
23. Wind?	1	2	3	4	□
24. Ventilation system or air conditioner?	1	2	3	4	□
25. Rain and/or thunderstorms?	1	2	3	4	□
26. Wind turbines?	1	2	3	4	□
27. Construction?	1	2	3	4	□
28. Other (please specify):					
If you would like to elaborate on any of your answers to the above questions, please do so here:					

How likely are you to doze off in the following situations (in contrast to just feeling tired)?

Situation	0=would never doze	1=slight chance of dozing	2=moderate chance of dozing	3=high chance of dozing
29. Sitting and reading	0	1	2	3
30. Watching TV	0	1	2	3
31. Sitting, inactive in a public place (e.g., a theater or a meeting	0	1	2	3
32. As a passenger in a car for an hour without a break	0	1	2	3
33. Lying down to rest in the afternoon when circumstances permit	0	1	2	3
34. Sitting and talking to someone	0	1	2	3
35. Sitting quietly after a lunch without alcohol	0	1	2	3
36. In a car, while stopped for a few minutes in traffic	0	1	2	3

Please rate the current severity of your inability to fall asleep or remain asleep in the following table: (If you don't have sleep problem, please choose the "none" option).

	None	Mild	Moderate	Severe	Very Severe
37. Difficulty falling asleep	1	2	3	4	5
38. Difficulty staying asleep	1	2	3	4	5
39. Problem waking up too early	1	2	3	4	5

40. How satisfied/dissatisfied are you with your current sleep pattern?

Very Satisfied	Moderately Satisfied			Very Dissatisfied
1	2	3	4	5

Please Skip questions (41 – 44) if you don't have a sleep problem.

41. To what extent do you consider your sleep problem to interfere with your daily functioning (e.g daytime fatigue, ability to work/daily chores, concentration, memory, mood, etc)?

Not at all	A little	Somewhat	Much	Very much
1	2	3	4	5

42. How noticeable to others do you think your sleeping problem is in terms of impairing the quality of your life?

Not at all	A little	Somewhat	Much	Very much
1	2	3	4	5

43. How concerned are you about your current sleep problem?

Not at all	A little	Somewhat	Much	Very much
1	2	3	4	5

44. To what extent do you believe the following factors are contributing to your sleep problem?

	None	Mild	Moderate	Severe	very severe
Racing thoughts at night	1	2	3	4	5
Muscular tension/pain	1	2	3	4	5
Bad sleeping habits	1	2	3	4	5
Natural aging process	1	2	3	4	5
Noise from outside	1	2	3	4	5

45. After a poor night's sleep, which of the following problems do you experience on the next day? Please circle all those that apply.

a. Daytime fatigue: tired, exhausted, washed out, sleepy
b. Difficulty functioning: performance impairment at work/daily chores. Difficulty concentrating, memory problems
c. Mood problems: irritable, tense, nervous, groggy, depressed, anxious, grouchy, hostile, angry, confused
d. Physical symptoms: muscle aches/pains, light-headed, headache, nausea, heartburn, muscle tension
e. None

References

Bakker, R.H., Pedersen, E., van den Berg, G.P., Stewart, R.E., Lok, W., Bouma, J., 2012. Impact of wind turbine sound on annoyance, self-reported sleep disturbance and psychological distress. Sci. Total Environ. 425, 42–51. http://dx.doi.org/10.1016/j.scitotenv.2012.03.005.

Beaudreau, S., Spira, A., Stewart, A., 2012. Validation of the Pittsburgh sleep quality index and the epworth sleepiness scale in older black and white women. Sleep. Med. 13 (1), 36–42.

Brotman, D.J., Golden, S.H., Wittstein, I.S., 2007. The cardiovascular toll of stress. Lancet 370 (9592), 1089–1100.

Buysse, D., Reynolds, C., Monk, T., 1989. The Pittsburgh sleep quality index: a new instrument for psychiatric practice and research. Psychiatry Res. . http://dx.doi.org/10.1016/0165–1781(89)90047–4

Canadian Wind Energy Association, 2016. Home - Canadian Wind Energy Association. Available: http://canwea.ca/ (accessed 17.01.16).

Claeson, A., Lidén, E., Nordin, M., Nordin, S., 2013. The role of perceived pollution and health risk perception in annoyance and health symptoms: a population-based study of odorous air pollution. Int. Arch. Occup. Environ. Health 86 (3), 367–374.

Dang-Vu, T.T., McKinney, S.M., Buxton, O.M., Solet, J.M., Ellenbogen, J.M., 2010. Spontaneous brain rhythms predict sleep stability in the face of noise. Curr. Biol. 20, 626–627. http://dx.doi.org/10.1016/j.cub.2010.06.032.

Ellenbogen, J.M., Grace, S., Heiger-Bernays, W.J., Manwell, J.F., Mills, D.A., Sullivan, K. A., 2012. Wind Turbine Health Impact Study. Report of Independent Expert Panel. Prepared for: Massachusetts Department of Environmental Protection. Massachusetts Department of Health.

Fritschi, L., Brown, L., Kim, R., 2011. Burden of disease from environmental noise—Quantification of healthy life years lost in Europe, WHO European Centre for Environment and Health.

Guastella, A., Moulds, M., 2007. The impact of rumination on sleep quality following a stressful life event. Pers. Individ. Differ. 42 (6), 1151–1162.

Johns, M.W., 1991. A new method for measuring daytime sleepiness: the Epworth sleepiness scale. Sleep . http://dx.doi.org/10.1016/j.sleep.2007.08.004.

Krogh, C.M.E., Gillis, L., Kouwen, N., Aramini, J., 2011. WindVOiCe, a self-reporting survey: adverse health effects, industrial wind turbines, and the need for vigilance monitoring. Bull. Sci. Technol. Soc. 31, 334–345. http://dx.doi.org/10.1177/0270467611412551.

Kuwano, S., Yano, T., Kageyama, T., 2013. Social survey on community response to wind turbine noise. Internoise 2013, 1–10.

Magari, S., Rohr, A., Smith, C., Schiff, M., 2014. Evaluation of community response to wind turbine-related noise in Western New York State. Noise Health 16, 228. http://dx.doi.org/10.4103/1463-1741.137060.

McCunney, R., Mundt, K., 2014. Wind turbines and health: a critical review of the scientific literature. J. Occup. Environ. Med. 56 (11), e108–e130.

Mcmahan, S., Meyer, J., 1995. Symptom prevalence and worry about high voltage transmission lines. Environ. Res. 70 (2), 114–118.

Michaud, D., Feder, K., Keith, S., Voicescu, S., 2015. Effects of wind turbine noise on self-reported and objective measures of sleep. Sleep.

Moffatt, S., Mulloli, T., Bhopal, R., 2000. An exploration of awareness bias in two environmental epidemiology studies. Epidemiology 11 (2), 199–208.

Morin, C., Barlow, D., 1993. Insomnia: Psychological Assessment and Management 104. Guilford Press,, New York, pp. 205–207.

Nissenbaum, M., Aramini, J., Hanning, C., 2012. Effects of industrial wind turbine noise on sleep and health. Noise Heal 14, 237. http://dx.doi.org/10.4103/1463–1741.102961.

Onakpoya, I.J., O'Sullivan, J., Thompson, M.J., Heneghan, C.J., 2015. The effect of wind turbine noise on sleep and quality of life: a systematic review and meta-analysis of observational studies. Environ. Int. 82, 1–9. http://dx.doi.org/10.1016/j.envint.2015.04.014.

Paller, C, 2014. Exploring the Association between Proximity to Industrial Wind Turbines and Self-Reported Health Outcomes in Ontario,Canada.

Pawlaczyk-Łuszczyńska, M., Dudarewicz, A., Zaborowski, K., Zamojska-Daniszewska, M., Waszkowska, M., 2014. Evaluation of annoyance from the wind turbine noise: a pilot study. Int. J. Occup. Med. Environ. Health 27, 364–388. http://dx.doi.org/10.2478/s13382–014–0252–1.

Pedersen, E., 2011. Health aspects associated with wind turbine noise—Results from three field studies. Noise Control Eng. J. 59, 47. http://dx.doi.org/10.3397/1.3533898.

Pedersen, E., Persson Waye, K., 2007. Wind turbine noise, annoyance and self-reported health and well-being in different living environments. Occup. Environ. Med. 64, 480–486. http://dx.doi.org/10.1136/oem.2006.031039.
Pedersen, E., Persson Waye, K., 2004a. Perception and annoyance due to wind turbine noise—a dose–response relationship. J. Acoust. Soc. Am. 116, 3460. http://dx.doi.org/10.1121/1.1815091.
Pedersen, E., Persson Waye, K., 2004b. Perception and annoyance due to wind turbine noise. J. Acoust. Soc. Am. 116, 3460–3470. http://dx.doi.org/10.1121/1.1815091.
Petrie, K., Broadbent, E., 2005. Worries about modernity predict symptom complaints after environmental pesticide spraying. Psychosom. Med. 67 (5), 778–782.
Petrie, K.J., Sivertsen, B., Hysing, M., Broadbent, E., Moss-Morris, R., Eriksen, H.R., Ursin, H., 2001. Thoroughly modern worries. J. Psychosom. Res. 51, 395–401. http://dx.doi.org/10.1016/S0022–3999(01)00219–7.
Ramakrishnan, R., Seharwat, V., 2015. Evaluation of sound propagation from wind. ICSV22, pp. 12–16.
Segerstrom, S.C., Miller, G.E., 2004. Psychological stress and the human immune system: a meta-analytic study of 30 years of inquiry. Psychol. Bull. 130 (4), 601.
Shepherd, D., Mcbride, D., Welch, D., Dirks, K.N., Hill, E.M., 2011a. Evaluating the impact of wind turbine noise on health- related quality of life. pp. 1–5. doi:10.4103/1463-1741.85502.
Shepherd, D., Welch, D., Hill, E., McBride, D., Dirks, K., 2011b. Evaluating the impact of wind turbine noise on health-related quality of life. Noise Health 13, 333. http://dx.doi.org/10.4103/1463–1741.85502.
Taylor, J., Eastwick, C., Wilson, R., Lawrence, C., 2013. The influence of negative oriented personality traits on the effects of wind turbine noise. Pers. Individ. Differ. 54, 338–343. http://dx.doi.org/10.1016/j.paid.2012.09.018.
Van den Berg, G.P., 2004. Effects of the wind profile at night on wind turbine sound. J. Sound. Vib. 277 (4), 955–970.
van den Berg, F., Pedersen, E., Bouma, J., Bakker, R., 2008. Visual and acoustic impact of wind turbine farms on residents. FP6-2005-Science-and-Society-20, Specific Support Action, Project, (044628).
Wolsink, M., Sprengers, M., Keuper, A., 1993. Annoyance from wind turbine noise on sixteen sites in three countries. In: Proceedings of the European Community Wind Energy Conference, pp. 273–276.
University of Maryland Medical Center, 2016. Sleepiness Scale. Available: http://ummidtown.org/programs/sleep/health/quizzes/sleepiness (accessed 20.01.16).