Environmental Research 142 (2015) 227–238

Contents lists available at ScienceDirect

Environmental Research

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

An assessment of quality of life using the WHOQOL-BREF among participants living in the vicinity of wind turbines ☆

Katya Feder [a], David S. Michaud [a,*], Stephen E. Keith [a], Sonia A. Voicescu [a], Leonora Marro [b], John Than [b], Mireille Guay [b], Allison Denning [c], Tara J. Bower [d], Eric Lavigne [e], Chantal Whelan [f], Frits van den Berg [g]

[a] Health Canada, Environmental and Radiation Health Sciences Directorate, Consumer & Clinical Radiation Protection Bureau, 775 Brookfield Road, Ottawa, Ontario, Canada
[b] Health Canada, Population Studies Division, Biostatistics Section, 200 Eglantine Driveway, Tunney's Pasture, Ottawa, Ontario, Canada
[c] Health Canada, Environmental Health Program, Health Programs Branch, Regions and Programs Bureau, 1505 Barrington Street, Halifax, Nova Scotia, Canada
[d] Health Canada, Environmental and Radiation Health Sciences Directorate, Office of Science Policy, Liaison and Coordination, 269 Laurier Avenue West, Ottawa, Ontario, Canada
[e] Health Canada, Air Health Science Division, 269 Laurier Avenue West, Ottawa, Ontario, Canada
[f] Department of Psychiatry, University of Ottawa, c/o Carlington Community Health Center, 900 Merivale Road, Ottawa, Ontario, Canada
[g] GGD Amsterdam Public Health Service, Environmental Health Department, Nieuwe Achtergracht 100, Amsterdam, The Netherlands

ARTICLE INFO

Article history:
Received 21 February 2015
Received in revised form
24 June 2015
Accepted 30 June 2015
Available online 11 July 2015

Keywords:
WHOQOL-BREF
Wind turbine noise
Cross-sectional study
Quality of life
Annoyance

ABSTRACT

Living within the vicinity of wind turbines may have adverse impacts on health measures associated with quality of life (QOL). There are few studies in this area and inconsistent findings preclude definitive conclusions regarding the impact that exposure to wind turbine noise (WTN) may have on QOL. In the current study (officially titled the *Community Noise and Health Study or CNHS*), the World Health Organization QOL-BREF (WHOQOL-BREF) questionnaire provided an evaluation of QOL in relation to WTN levels among randomly selected participants aged 18–79 (606 males, 632 females) living between 0.25 and 11.22 km from wind turbines (response rate 78.9%). In the multiple regression analyses, WTN levels were not found to be related to scores on the Physical, Psychological, Social or Environment domains, or to rated QOL and Satisfaction with Health questions. However, some wind turbine-related variables were associated with scores on the WHOQOL-BREF, irrespective of WTN levels. Hearing wind turbines for less than one year (compared to not at all and greater than one year) was associated with improved (i.e. higher) scores on the Psychological domain ($p=0.0108$). Lower scores on both the Physical and Environment domains ($p=0.0218$ and $p=0.0372$, respectively), were observed among participants reporting high visual annoyance toward wind turbines. Personal benefit from having wind turbines in the area was related to higher scores on the Physical domain ($p=0.0417$). Other variables significantly related to one or more domains, included sex, age, marital status, employment, education, income, alcohol consumption, smoking status, chronic diseases and sleep disorders. Collectively, results do not support an association between exposure to WTN up to 46 dBA and QOL assessed using the WHOQOL-BREF questionnaire.

Abbreviations: ANOVA, Analysis of Variance; CNHS, Community Noise and Health Study; dBA, A-weighted decibel; dBC, C-weighted decibel; MW, megawatt; ON, Ontario; PEI, Prince Edward Island; QOL, quality of life; SAS, Statistical Analysis System; SF-36®, Short Form Health Survey; WHO, World Health Organization; WHOQOL, World Health Organization Quality Of Life; WHOQOL-BREF, World Health Organization Quality Of Life—abbreviated version of the WHOQOL 100; WTN, wind turbine noise

☆Funding Source and Ethics Approval: The study was funded by Health Canada. This study was approved by the Health Canada and Public Health Agency of Canada Review Ethics Board in accordance with the Tri-Council Policy Statement Ethical Conduct For Research Involving Humans (TCPS) (Protocol #2012-0065 and #2012-0072).
* Corresponding author.
E-mail address: david.michaud@hc-sc.gc.ca (D.S. Michaud).

http://dx.doi.org/10.1016/j.envres.2015.06.043

1. Introduction

Quality of life (QOL) evaluation in health research emerged in the 1970s in order to supplement traditional morbidity and mortality outcomes. The meaning of the concept of QOL and how it can be reliably evaluated has been studied for many years. The World Health Organization (WHO) defines QOL as "*an individual's perception of their position in life in the context of the culture and value systems in which they live, and in relation to their goals, expectations, standards and concerns*" (WHOQOL Group, 1994). Quality of life is a global measure, broader than health status, inherently subjective and pertains to all aspects of life important to the person (Harrison et al., 1996; Molzahn and Pagé, 2006). There is evidence that dissatisfaction with environment, psychological and/or social domains may impact physical health and well-being in individuals (Guite et al., 2006; Silva et al., 2012).

The methodologies and tools used in environmental noise studies are wide-ranging and have included participant diaries, observational checklists, specialized questionnaires, validated health measures scales and/or QOL scales. The use of a validated measure can be advantageous in that psychometric evaluation such as validity and reliability testing has been completed. In addition, the use of a standardized measure facilitates comparisons across studies enabling trends in research to be more easily examined.

Many QOL studies have used the World Health Organization QOL (WHOQOL)-100, a questionnaire consisting of 100 items divided into multiple domains, which has demonstrated discrimination between healthy and ill populations (WHOQOL Group, 1998). An abbreviated 26-item version (i.e. WHOQOL-BREF) has also been used in numerous studies to evaluate perceptions of health. This questionnaire, developed using data from 30 international field centres, has been found to be an effective cross-cultural assessment of QOL with good to excellent psychometric properties of reliability and validity (Kalfoss et al., 2008; Skevington et al., 2004). The WHOQOL-BREF consists of 4 domains, Physical Health, Psychological, Social Relationships, and Environment. Each domain is comprised of multiple questions that are considered together in the derivation of each domain score. In addition to the 4 domains, the WHOQOL-BREF includes two standalone questions to assess rated QOL and Satisfaction with Health (WHOQOL Group, 1994).

Some environmental noise studies have utilized QOL measures to quantify and compare community response to different noise sources (Shepherd et al., 2010; Welch et al., 2013), with the general observation that increasing exposure to noise is associated with decreased QOL. As reliance on wind power as a source of energy increases, the introduction of wind farms into communities is sometimes resisted or negatively received based, at least in part, on the perception that exposure to wind turbine noise (WTN) has adverse impacts on health and QOL. In a review of literature related to the health effects of WTN, the Council of Canadian Academies (2015) concluded that the only health effect with sufficient evidence for a causal association with exposure to WTN was long term annoyance. Among the Council's key findings was an acknowledgement that there was a paucity of epidemiological studies to draw upon and those that did exist suffered from methodological problems that included, but were not limited to weak statistical power, bias, and lack of controls. Other reviews by researchers and government agencies have reached similar conclusions (Chief Medical Officer of Health Ontario, 2010; Knopper et al., 2014; MassDEP and MDPH, 2012; Merlin et al., 2014; Oregon Health Authority, 2013; Schmidt and Klokker, 2014).

In comparison to the large body of scientific literature examining the response to transportation noise, there are few original epidemiological studies that have investigated the possible impact on QOL among communities living within the vicinity of wind turbines and among those studies, only a limited number of them have utilized validated instruments to examine QOL (Onakpoya et al., 2014). Shepherd et al. (2011) reported that individuals who lived near a wind farm scored worse on general QOL and on the Physical and Environment domains of the WHOQOL-BREF compared to a geographically and socioeconomically matched group living at least 8 km from any wind farms. Conflicting results were found in two other wind turbine studies (Mroczek et al., 2012; Nissenbaum et al., 2012), where QOL was evaluated using a Short Form Health Survey (SF-36®) to examine health outcomes in individuals who lived close to wind turbines and those who lived further away. Nissenbaum et al. (2012) reported lower scores on the mental, but not physical component of the SF-36®, among 38 participants living between 375 m and 1400 m of a wind turbine when compared to 41 participants living between 3.3 km and 6.6 km from a wind turbine. This is in contrast to the findings from a much larger study by Mroczek et al. (2012) where *improved* QOL for all SF-36® domains was found among those living at the closest distance to a wind farm (i.e. <700 m), in comparison to those living beyond 1500 m. In an extended analysis, Mroczek et al. (2015) reaffirmed a higher reported QOL among participants living closer to wind turbines, relative to those living further away and reported that the stage of the wind farm development was an important factor in this regard. These incongruent results, in addition to their methodological issues, small sample sizes and low response rates underscored the need for more research.

Where wind turbines are concerned, it has also been shown that there can be adverse community reactions to features that go beyond WTN emissions. In particular, self-reported health effects have been attributed to features such as shadow flicker. Wind turbine shadow flicker is a phenomenon caused by the flickering effect of rotating blades periodically casting shadows over some but not all neighbouring properties and through windows (Bolton, 2007; Department of Energy and Climate Change (DECC), 2011; Saidur et al., 2011). With their blade length accounted for, utility-scale wind turbines can reach 130 m and wind farms can include dozens of wind turbines. Their height necessitates aircraft warning signals (e.g. blinking lights on the turbine nacelle) and the visual intrusion of wind turbines on the landscape, in addition to WTN, are features that are known to underlie the response to wind turbines (Harding et al., 2008; Pedersen and Larsman, 2008; Pohl et al., 1999; Smedley et al., 2010; van den Berg et al., 2008). While the annoyance response to shadow flicker and/or blinking lights on top of wind turbines has been investigated (Katsaprakakis, 2012; Pohl et al., 2000, 2012), the only field study to assess QOL measures as a function of shadow flicker exposure was published in German by Pohl et al. (1999). In this study, exposure to shadow flicker was related to decreased QOL and elevated annoyance (Pohl et al., 1999).

In assessing the potential contribution that exposure to wind turbines may have on health and QOL, it is important to consider personal and situational factors that may influence reported QOL. For instance, expectations of negative reactions and worry about perceived risk may play a role in self-reported health impacts related to wind turbines (Crichton et al., 2014; Henningsen and Priebe, 2003). Others have found attitudinal factors, personality traits and personal benefit from wind turbines influenced the magnitude of the annoyance to wind turbines; which in turn may be responsible for reported health effects (Chapman et al., 2013; Rubin et al., 2014; Taylor et al., 2013; Pedersen et al., 2009). Regardless of the mechanisms, it is well known that self-reported health is highly correlated with QOL (Bowling, 1995; Hutchinson et al., 2004).

The objective of the present paper was to assess self-reported QOL among individuals living in areas with varying levels of WTN exposure. To this end, the WHOQOL-BREF was administered as part of Health Canada's CNHS. The underlying hypothesis in the current study is that if QOL is adversely impacted by WTN exposure, participants living in areas with higher exposures to WTN would yield lower scores on the WHOQOL-BREF.

2. Methods

2.1. Sample design

2.1.1. Target population, sample size and sampling frame strategy

A detailed description of the study design and methodology, the target population, final sample size and allocation of participants, as well as the strategy used to develop the sampling frame has been described by Michaud et al. (2013) and Michaud (2015). Briefly, the study locations were drawn from areas in southwestern Ontario (ON) and Prince Edward Island (PEI) where there were a sufficient number of dwellings within the vicinity of wind turbine installations. There were 2004 potential dwellings identified from the ON and PEI sampling regions, which included 12 and 6 wind farms, representing a total of 315 and 84 wind turbines respectively. The wind turbine electrical power outputs ranged between 660 kW and 3 MW (average 2.0 ± 0.4 MW). All turbines were modern monopole design with 3 pitch controlled rotor blades (~80 m diameter) upwind of the tower and most had 80 m hub heights. All dwellings within approximately 600 m from a wind turbine and a random selection of dwellings between 0.60 and 11.22 km were selected from which one person per household between the ages of 18 and 79 years was randomly chosen to participate. Several factors influenced the determination of the final sample size, including having adequate statistical power to assess the study objectives, and the time required for collection of data (Michaud et al., 2013). Taken together, it was determined that a sample size of approximately 1100 would be required to meet study objectives. It was likely that this sample size would be sufficient to detect statistically significant impacts on QOL in the current study given that Shepherd et al. (2011) reported a statistically significant impact on QOL using the WHOQOL-BREF among 39 participants living near wind turbines when compared to 158 participants living further away.

2.1.2. Wind turbine sound pressure levels at dwellings

Outdoor wind turbine sound pressure levels were estimated at each dwelling using both ISO 9613-1 and ISO 9613-2 (ISO 1993, 1996) as incorporated in the commercial software CadnaA version 4.4 (DataKustik GmbH®, 2014). The calculations included all wind turbines within a radius of 10 km, and were based on manufacturers' octave band sound power spectra at 8 m/s, standardized wind speed and favourable sound propagation conditions. Favourable conditions assume the dwelling is located downwind of the noise source, or a stable atmosphere and a moderate ground based temperature inversion. Although different wind speeds and temperature difference could not be considered in the model calculations due to a lack of relevant data, 8 m/s was considered a reasonable estimate of the highest noise exposure conditions. The manufacturers' data were verified for consistency using on-site measurements of wind turbine sound power. The standard deviation in sound levels was estimated to be 4 dB up to 1 km, and at 10 km the uncertainty was estimated to be between 10 dB and 26 dB. While calculations based on predictions of WTN levels reduces the risk of misclassification compared to direct measurements, the risk remains to some extent.

Outdoor WTN levels were also modeled in C-weighted values (dBC), however due to the similarity of the sound power spectra, dBC levels were highly correlated with dBA levels such that there was no additional benefit in using dBC in the current study. Unless otherwise stated, all dB references are A-weighted. A-weighting filters out high and low frequencies in a sound that the human auditory system is less sensitive to at low sound pressure levels.

2.2. Data collection

2.2.1. Questionnaire development, administration and refusal conversion strategies

The questionnaire instrument included the following modules: noise annoyance, health effects, sleep quality, perceived stress, lifestyle behaviours and prevalent chronic disease. QOL was assessed using the WHOQOL-BREF. This 26 item QOL instrument has shown good to excellent psychometric properties and is cross culturally sensitive (WHOQOL Group, 1998). The WHOQOL-BREF generates a profile and score for each of the 4 QOL domains; questions are centered around the meaning respondents attribute to each aspect of life and how problematic or satisfactory they perceive them to be (Skevington et al., 2004). The Physical Health domain includes questions pertaining to sleep, energy, mobility, the extent to which pain prevents performance of necessary tasks, the need for medical treatment to function in daily life, level of satisfaction with their capacity for work. The Psychological domain focuses on the ability to concentrate, self-esteem, body image, spirituality i.e. the extent to which they feel their life is meaningful, the frequency of positive or negative feelings i.e. blue mood, despair, anxiety, depression. The Social Relationships domain includes questions pertaining to satisfaction with personal relationships, social support systems and sexual satisfaction. The fourth domain, the Environment, includes questions related to safety and security, home and physical environment satisfaction, finance i.e. does the respondent have enough money to meet their needs, health/social care availability, information and leisure activity accessibility and transportation satisfaction (Skevington et al., 2004). In addition to the 4 domains, the WHOQOL-BREF includes two stand-alone questions, one pertaining to the respondents' rated QOL, and one related to their Satisfaction with Health. The WHOQOL-BREF instructions specify that this questionnaire is to be used without modification (WHOQOL-BREF, 1996).

Throughout data collection, the Health Canada study was officially referred to as the "*Community Noise and Health Study*" in an attempt to mask the true intent of the study, which was to investigate the association between health and WTN exposure. This approach is commonly used in epidemiological studies to avoid a disproportionate contribution from any group that may have distinct views regarding a study subject, such as wind turbines. Data collection took place through in-person interviews between May 2013 and September 2013 in southwestern ON and PEI. Once a roster of all adults, 18–79 years, living in the dwelling was compiled, a computerized method was used to randomly select one adult per household. No substitution was permitted; therefore, if the targeted individual was not at home or unavailable, alternate arrangements were made to encourage participation at a later time.

All 16 interviewers were instructed to make every reasonable attempt to obtain interviews, which included visiting the dwelling at various times of the day on multiple occasions and making contact by telephone when necessary. If the individual refused to participate, they were then contacted a second time by either the senior interviewer or another interviewer. If, after a second contact, respondents refused to participate, the case was coded as a final refusal.

2.2.2. Statistical analysis

The 4 domains are factors based on the 26 questions which make up the WHOQOL-BREF. As such they are treated as continuous outcomes with each domain score converted to scores ranging between 4 and 20, in accordance with the first transformation method outlined in the WHOQOL-BREF scoring instructions (WHOQOL-BREF 1996). The two stand-alone questions related to QOL rating and Satisfaction with Health were analysed separately, as recommended by WHOQOL-BREF (1996). These two questions include five point response categories for QOL: "*very poor*", "*poor*", "*neither poor nor good*", "*good*" and "*very good*" and for Satisfaction with Health: "*very dissatisfied*", "*dissatisfied*", "*neither satisfied nor dissatisfied*", "*satisfied*" and "*very satisfied*". Analysis was performed after collapsing the bottom two categories (i.e., for QOL "*very poor*" and "*poor*"; for Satisfaction with Health "*very dissatisfied*" and "*dissatisfied*") and comparing them to the top three. This approach produced the following derived variables: "*poor QOL*" vs. "*good QOL*" and "*dissatisfied with own health*" vs. "*satisfied with own health*". Therefore, unlike the 4 domains, these two questions are treated as binary outcomes.

The relationship between sensitivity to noise, QOL and WTN exposure was also considered. Sensitivity to noise was scored on the following five-point response scale: "*not at all*", "*slightly*", "*moderately*", "*very*" and "*extremely*". The response scale for this variable was dichotomized with "*high sensitivity*" including the "*very*" and "*extremely*" categories; and "*low sensitivity*" including "*not at all*", "*slightly*" and "*moderately*" categories. A sensitivity analysis was conducted to investigate the advantage of keeping the noise sensitivity as a 3 scale parameter ("*highly*", "*moderately*", "*low*"). Conclusions in the analysis were similar whether noise sensitivity was included as a dichotomized scale or a 3 scale parameter (i.e. there was no statistical difference in QOL domains between those having moderate noise sensitivity and low noise sensitivity). No additional information was gained by including the 3 scale parameter (results not shown).

The analysis for continuous and categorical outcomes follows the description outlined in Michaud et al. (2013). Final WTN categories (dBA) were defined as follows: {<25; 25–<30; 30–<35; 35–<40; and 40–46}. Univariate analyses of WHOQOL-BREF domains, rated QOL and Satisfaction with Health questions were carried out in relation to a number of variables which could conceivably be expected to influence QOL. The analysis of each variable only adjusts for WTN exposure category and province, and interpretation of any individual relationship must therefore be made with caution. Multiple linear regression models for the domains (continuous outcomes) and multiple logistic regression models for the two stand-alone questions (binary outcomes) were developed using the stepwise method with a 20% significance entry criterion (determined from the univariate analyses, see Supplemental material). A 10% significance criterion was applied to retain variables in the model. The stepwise regression was carried out in three different ways: (1) the base model included exposure to WTN categories and province; (2) the base model included exposure to WTN categories, province and an adjustment for participants who received personal benefit; and (3) the base model included exposure to WTN categories and province, conditional for those who received no personal benefit. In cases when cell frequencies were small (i.e. <5) in the contingency tables or logistic regression models, exact tests were used as described in Agresti (2002) and Stokes et al. (2000). Since this latter technique is very computationally intensive, the WTN level categories had to be treated as a continuous variable. All models were adjusted for provincial differences with province initially considered as an effect modifier. Since the interaction was not statistically significant, province was treated as a confounder in the linear and logistic regression models. Statistical analysis was performed using Statistical Analysis System (SAS) version 9.2. A 5% statistical significance level was implemented throughout unless otherwise stated. Pairwise tests or multiple comparisons were only conducted when the overall significance of the variable was less than 0.05. In addition, Tukey (for continuous outcomes) and Bonferroni (for binary outcomes) corrections were carried out to account for all pairwise comparisons to ensure that the overall Type I (false positive) error rate was less than 0.05. Only variables which are conceptually, and/or have been previously found to be related to QOL were included in the analysis.

3. Results

3.1. *Wind turbine sound pressure levels at dwellings, response rates and sample characteristics*

Calculated outdoor sound pressure levels reached levels as high as 46 dB. Calculations are representative of typical worst case long term (1 year) average WTN levels. Initially, 2000 addresses were targeted, with 4 additional addresses added during field investigations. Of the 2004, 1570 addresses were considered to be valid dwellings, from which 1238 occupants agreed to participate in the study (606 males, 632 females). This produced a final calculated response rate of 78.9%. The 434 dwellings that were found to be out-of-scope was anticipated based on previous surveys carried out in rural Canadian areas and on Census data forecasting a higher out-of-scope dwelling rate in PEI compared to ON. A characterisation of the out-of-scope locations is provided in Michaud (2015).

Factors that might be expected to influence QOL, such as self-reported prevalence of chronic disease, health conditions, noise sensitivity and reporting to be highly sleep disturbed in any way, for any reason, were all found to be equally distributed across WTN categories (Michaud, 2015).

3.2. *Internal consistency of the WHOQOL-BREF domains*

Table 1 presents the summary statistics and Cronbach's alpha for the WHO domains. Cronbach's alpha, a measure of the internal consistency of the facets/domains, was above the recommended 70% for all domains except Social Relationships (Cronbach's alpha=66%). This indicates that the correlation within the data for the three items used to determine the Social Relationships domain was found to be questionable within the current study. Caution is therefore advised when interpreting the results within this domain. In the case of a Cronbach's alpha of <0.70, it is recommended that the item(s) least correlated with the construct be dropped one at a time. However, this approach would yield a Social domain that consists of only two questions. Furthermore, analysis of individual items is not recommended as there is a risk of considerable random measurement error (McIver and Carmines, 1981; Nunnally and Bernstein, 1994; Spector, 1992).

3.3. *Univariate analysis of variables related to the WHOQOL-BREF*

Univariate analyses of WHOQOL-BREF domains and rated QOL and Satisfaction with Health questions were carried out in relation to a number of variables including, but not limited to, chronic

Table 1
Summary of the WHOQOL-BREF domains.

Domain	Mean (SD)	Range	Cronbach's alpha	Standardized Cronbach's alpha	*n*
Physical Health	16.06 (3.03)	(4, 20)	0.86	0.86	1236
Psychological	15.99 (2.43)	(4, 20)	0.79	0.80	1236
Social Relationships	16.46 (2.83)	(4, 20)	0.64	0.66	1233
Environment	16.47 (2.20)	(7, 20)	0.72	0.73	1237

SD, standard deviation.

Table 2a
Multiple linear regression model: Physical Health domain.

Variable	Groups in Variable[a]	LSM (95%CI)[b] (R^2=0.45, n=945)[e]	PWC[c]	p-Value[d]
WTN levels (dB)	< 25 (n=84)	13.11 (12.32, 13.90)		0.1689
	25– < 30 (n=95)	13.35 (12.55, 14.15)		
	30– < 35 (n=304)	13.31 (12.65, 13.98)		
	35– < 40 (n=521)	13.71 (13.08, 14.34)		
	40–46 (n=234)	13.45 (12.81, 14.10)		
Province	PEI (n=227)	13.49 (12.79, 14.19)		0.3415
	ON (n=1011)	13.28 (12.72, 13.84)		
Personal benefit	Yes (n=110)	13.68 (12.91, 14.45)	A	0.0415
	No (n=1075)	13.10 (12.57, 13.62)	B	
Employed	Yes (n=722)	13.85 (13.22, 14.49)	A	< 0.0001
	No (n=515)	12.92 (12.31, 13.53)	B	
Marital status	Married/common-law (n=848)	13.47 (12.89, 14.05)	AB	0.0141
	Widowed/separated/divorced (n=215)	13.76 (13.10, 14.43)	A	
	Single, never been married (n=172)	12.92 (12.20, 13.65)	B	
Audible rail noise	Yes (n=227)	13.58 (12.91, 14.26)		0.0568
	No (n=1011)	13.19 (12.61, 13.77)		
Visual annoyance to turbines	High (n=159)	13.11 (12.41, 13.81)	A	0.0193
	Low (n=1075)	13.67 (13.09, 14.24)	B	
Alcohol use	Do not drink alcohol (n=274)	13.16 (12.52, 13.80)	AB	0.0069
	≤ 3 Times per month (n=474)	13.06 (12.44, 13.68)	A	
	1–3 Times/week (n=325)	13.61 (12.96, 14.26)	B	
	≥ 4 Times/week (n=164)	13.72 (13.00, 14.44)	B	
Smoking status	Current (n=284)	13.12 (12.48, 13.76)	A	0.0273
	Former (n=423)	13.38 (12.74, 14.02)	AB	
	Never (n=531)	13.66 (13.02, 14.29)	B	
Migraines[f]	Yes (n=289)	12.99 (12.34, 13.63)	A	0.0001
	No (n=948)	13.79 (13.17, 14.40)	B	
Dizziness	Yes (n=273)	12.85 (12.21, 13.50)	A	< 0.0001
	No (n=965)	13.92 (13.31, 14.54)	B	
Tinnitus	Yes (n=293)	13.16 (12.53, 13.80)	A	0.0237
	No (n=944)	13.61 (12.99, 14.22)	B	
Chronic pain	Yes (n=293)	12.21 (11.58, 12.84)	A	< 0.0001
	No (n=943)	14.56 (13.93, 15.19)	B	
Arthritis	Yes (n=402)	13.12 (12.50, 13.74)	A	0.0043
	No (n=835)	13.66 (13.03, 14.29)	B	
Diabetes	Yes (n=113)	13.06 (12.33, 13.79)	A	0.0197
	No (n=1123)	13.72 (13.14, 14.29)	B	
Medication for high blood pressure, past month	Yes (n=370)	13.14 (12.51, 13.77)	A	0.0093
	No (n=866)	13.63 (13.01, 14.25)	B	
Chronic bronchitis/emphysema/COPD	Yes (n=71)	12.87 (12.07, 13.67)	A	0.0027
	No (n=1165)	13.90 (13.36, 14.45)	B	
Diagnosed sleep disorder	Yes (n=119)	12.84 (12.14, 13.54)	A	< 0.0001
	No (n=1119)	13.93 (13.33, 14.53)	B	

COPD, chronic obstructive pulmonary disease, LSM, least square mean; ON, Ontario; PEI, Prince Edward Island; PWC, pairwise comparison; WTN, wind turbine noise. Table footnotes are applicable for Tables 2a–2d.

[a] The sample size for each variable does not always sum to the study sample size (n=1238) as not all participants responded to each question.

[b] Based on the multiple linear regression model adjusted for all other variables in the model and 95% Tukey adjusted confidence interval.

[c] Where overall p-value is < 0.05, pairwise comparisons were conducted. After adjusting for multiple comparisons, groups with the same letter are statistically similar, groups with different letters are statistically different.

[d] Overall p-value from multiple linear regression model testing the significance of the variable.

[e] Only participants with complete records were considered in the final model.

[f] Migraines or headaches (including nausea, vomiting, sensitivity to light and sound).

diseases, self-reported health conditions, socio-demographic characteristics, audibility of wind turbines, WTN annoyance, annoyance with the visual aspect of wind turbines and other variables related to the perception of wind turbines, which could conceivably be expected to influence QOL. Included among these variables was personal benefit. In this study, personal benefit refers to those who reported to benefit in any way from having a wind turbine in their area, including receiving rent, payments or other indirect benefits from community improvements. The primary objective in the current analysis was to use multiple regression models to identify the variables that have the strongest statistical association with the WHOQOL-BREF domains and rated QOL and Satisfaction with Health questions. All explanatory variables significant at the 20% level in the univariate analysis were considered in the multiple regression models. The univariate analyses are available in Supplemental material.

3.4. Multiple linear regression models for WHOQOL-BREF domains

Multiple linear regression models to describe the variability in the WHOQOL-BREF domains were developed using stepwise regression with 20% significance entry criteria for predictors and a 10% significance criteria to remain in the model. A complete list of these variables has been made available in Supplemental material. The final models for the three approaches to stepwise regression as listed in the statistical methods section produced nearly

Table 2b
Multiple linear regression model: Psychological domain.

Variable	Groups in Variable	LSM (95%CI) (R^2=0.25, n=949)	PWC	p-Value
WTN levels (dB)	< 25 (n=84)	15.13 (14.38, 15.88)		0.6002
	25– < 30 (n=95)	14.98 (14.19, 15.76)		
	30– < 35 (n=304)	14.79 (14.17, 15.40)		
	35– < 40 (n=521)	15.02 (14.45, 15.58)		
	40–46 (n=234)	14.81 (14.23, 15.39)		
Province	PEI (n=227)	14.63 (14.00, 15.27)	A	0.0018
	ON (n=1011)	15.26 (14.72, 15.79)	B	
Personal benefit from having wind turbines in the area	Yes (n=110)	15.13 (14.43, 15.84)		0.1512
	No (n=1075)	14.76 (14.26, 15.26)		
Age group	≤ 24 (n=72)	15.33 (14.42, 16.25)	AB	0.0230
	25-44 (n=331)	14.71 (14.12, 15.30)	AB	
	45-64 (n=547)	14.60 (14.07, 15.13)	A	
	65+ (n=288)	15.14 (14.53, 15.74)	B	
Marital status	Married/common-law (n=848)	15.33 (14.77, 15.89)	A	0.0013
	Widowed/separated/divorced (n=215)	14.71 (14.07, 15.36)	B	
	Single, never been married (n=172)	14.80 (14.15, 15.45)	AB	
Employed	Yes (n=722)	15.14 (14.56, 15.72)	A	0.0265
	No (n=515)	14.75 (14.17, 15.33)	B	
Level of education	≤ High school (n=678)	14.62 (14.06, 15.18)	A	0.0109
	Trade/certificate/college (n=469)	14.76 (14.18, 15.34)	A	
	University (n=90)	15.45 (14.75, 16.15)	B	
Sensitivity to noise	High (n=175)	15.12 (14.49, 15.75)		0.0947
	Low (n=1059)	14.77 (14.22, 15.32)		
Alcohol use	Do not drink alcohol (n=274)	14.92 (14.33, 15.51)		0.0565
	≤ 3 Times per month (n=474)	14.67 (14.10, 15.25)		
	1–3 Times/week (n=325)	15.16 (14.55, 15.77)		
	≥ 4 times/week (n=164)	15.03 (14.35, 15.70)		
Number of years hearing the wind turbines	Do not hear wind turbines (n=651)	14.54 (14.02, 15.05)	A	0.0108
	Less than 1 year (n=61)	15.54 (14.72, 16.36)	B	
	1 year or more (n=522)	14.76 (14.19, 15.32)	A	
Migraines	Yes (n=289)	14.74 (14.15, 15.34)	A	0.0364
	No (n=948)	15.14 (14.57, 15.72)	B	
Dizziness	Yes (n=273)	14.32 (13.72, 14.92)	A	< 0.0001
	No (n=965)	15.57 (15.00, 16.14)	B	
Tinnitus	Yes (n=293)	14.72 (14.12, 15.31)	A	0.0138
	No (n=944)	15.17 (14.60, 15.74)	B	
Chronic pain	Yes (n=293)	14.45 (13.85, 15.05)	A	< 0.0001
	No (n=943)	15.44 (14.87, 16.00)	B	
Diabetes	Yes (n=113)	14.72 (14.03, 15.40)		0.0721
	No (n=1123)	15.17 (14.66, 15.69)		
Diagnosed sleep disorder	Yes (n=119)	14.25 (13.59, 14.91)	A	< 0.0001
	No (n=1119)	15.64 (15.10, 16.18)	B	

identical results to one another. Therefore, results are only presented for the regression method where the variables WTN, province and personal benefit were forced into the model.

Tables 2a–2d present a detailed account of the demographic, wind-turbine related, personal and health-related variables found to be most strongly associated with the WHOQOL-BREF domains. The final multiple linear regression models accounted for 16%, 24%, 25% and 45% of the variance in the Social Relationships, Environment, Psychological and Physical Health domains, respectively. As shown in Tables 2a–2d, WTN exposure was not found to be significant in any domain, even after adjusting for the other factors. Also, no differences between provinces were observed among domains with the exception of the Psychological domain, where ON had higher domain values than PEI (p=0.0018). A notable observation was that high visual annoyance with wind turbines was associated with lower scores on the Physical Health (Table 2a) and Environment (Table 2d) domains, p=0.01931 and p=0.0096, respectively.

3.5. Multiple logistic regression models, QOL, Satisfaction with Health

Multiple logistic regression models to describe the variability in the two stand-alone questions of the WHOQOL-BREF (QOL and Satisfaction with Health) were also developed using stepwise regression with 20% significance entry criteria for predictors and a 10% significance criteria to remain in the model. A complete list of these variables has been made available in the Supplemental Material. The stepwise regression was carried out in a similar fashion as for the 4 domains i.e., (1) the base model included exposure to WTN categories and province; (2) the base model included exposure to WTN categories, province and an adjustment for participants who received personal benefit; and (3) the base model included exposure to WTN categories and province, conditional for those who received no personal benefit. The final models for the three approaches to stepwise regression listed above produced nearly identical results to one another. Therefore, results are only presented for the regression method where the variables WTN, province and personal benefit were forced into the model.

Multiple logistic regression models for prevalence of those who rated their QOL to be "*poor*" (includes the ratings "*very poor*" and "*poor*") and reported to be "*dissatisfied*" with their health (includes ratings "*very dissatisfied*" and "*dissatisfied*") are presented in

Table 2c
Multiple linear regression model: Social Relationships domain.

Variable	Groups in variable	LSM (95%CI) (R^2=0.16, n=987)	PWC	p-Value
WTN levels (dB)	<25 (n=84)	14.57 (13.73, 15.42)		0.7298
	25–<30 (n=95)	14.95 (14.07, 15.83)		
	30–<35 (n=304)	14.42 (13.72, 15.13)		
	35–<40 (n=521)	14.60 (13.92, 15.27)		
	40–46 (n=234)	14.59 (13.88, 15.29)		
Province	PEI (n=227)	14.43 (13.67, 15.19)		0.1225
	ON (n=1011)	14.82 (14.25, 15.40)		
Personal benefit from having wind turbines in the area	Yes (n=110)	14.58 (13.76, 15.39)		0.7560
	No (n=1075)	14.68 (14.12, 15.23)		
Sex	Male (n=606)	14.41 (13.75, 15.07)	A	0.0154
	Female (n=632)	14.84 (14.20, 15.49)	B	
Age group	≤24 (n=72)	15.27 (14.25, 16.29)	A	0.0029
	25-44 (n=331)	14.65 (13.96, 15.34)	A	
	45-64 (n=547)	14.04 (13.41, 14.67)	B	
	65+ (n=288)	14.55 (13.85, 15.26)	AB	
Marital status	Married/common-law (n=848)	15.52 (14.88, 16.17)	A	<0.0001
	Widowed/separated/divorced (n=215)	13.95 (13.22, 14.68)	B	
	Single, never been married (n=172)	14.41 (13.65, 15.16)	B	
Employed	Yes (n=722)	14.84 (14.19, 15.50)	A	0.0368
	No (n=515)	14.41 (13.75, 15.07)	B	
Façade type	Fully bricked (n=340)	15.13 (14.46, 15.80)	A	0.0012
	Partially bricked (n=218)	14.19 (13.44, 14.95)	B	
	No brick/other (n=680)	14.55 (13.92, 15.18)	B	
Audible rail noise	Yes (n=227)	14.42 (13.69, 15.15)		0.0742
	No (n=1011)	14.83 (14.24, 15.43)		
Migraines	Yes (n=289)	14.38 (13.68, 15.07)	A	0.0296
	No (n=948)	14.88 (14.24, 15.51)	B	
Dizziness	Yes (n=273)	14.22 (13.53, 14.91)	A	0.0004
	No (n=965)	15.03 (14.39, 15.67)	B	
Chronic pain	Yes (n=293)	14.32 (13.65, 14.99)	A	0.0049
	No (n=943)	14.93 (14.28, 15.58)	B	
Chronic bronchitis/emphysema/COPD	Yes (n=71)	14.16 (13.30, 15.03)	A	0.0140
	No (n=1165)	15.09 (14.53, 15.64)	B	
Diagnosed sleep disorder	Yes (n=119)	14.27 (13.50, 15.03)	A	0.0167
	No (n=1119)	14.99 (14.37, 15.60)	B	

Tables 3a and 3b. In both models there was no statistically significant association between WTN levels and the prevalence rates for reporting "*poor*" QOL or "*dissatisfied*" Satisfaction with Health, even after adjusting for the other demographic, wind-turbine related and personal and health-related variables (as listed in Tables 3a and 3b). Prevalence rates for both QOL and Satisfaction with Health were similar in both ON and PEI. Together, these variables accounted for 31% and 29% of the variance in rated QOL (Table 3a) and Satisfaction with Health, respectively (Table 3b).

A summary table highlighting all variables retained in the multiple regression models for the 4 WHOQOL-BREF domains and two stand-alone questions is presented as Table 4.

4. Discussion

The present study findings do not support an association between exposure to WTN up to 46 dBA and any of the WHOQOL-BREF domains (Physical Health, Psychological, Social Relationships and Environment) or the two stand-alone questions pertaining to rated QOL and Satisfaction with Health. Participants who were exposed to higher WTN levels did not rate their QOL or Satisfaction with Health significantly worse than those who were exposed to lower WTN levels, nor did they report having significantly worse outcomes in terms of factors that comprise the 4 domains. This is contrary to the findings of Shepherd et al. (2011) who also measured QOL using the WHOQOL-BREF questionnaire. Shepherd et al. (2011) reported significantly lower mean Physical and Environment domain scores and QOL rating among the 39 participants (drawn from 56 dwellings) within 2 km of a wind turbine compared to the 158 participants (drawn from 250 dwellings) that were located at least 8 km from a wind farm. It is difficult to compare these findings with the current study insofar as the participants living within 2 km of a wind turbine in Shepherd et al. (2011) were reportedly exposed to WTN levels ranging from 20 to 50 dB. This encompasses the entire range of exposure in the present study.

A study by Nissenbaum et al. (2012) assessed QOL using the SF-36® questionnaire and utilized an approach similar to Shepherd et al. (2011). Nissenbaum et al. (2012) compared QOL scores among two distance groups from two wind farms. These authors reported lower mean scores for the mental component of the SF-36® among a group of 38 participants from 65 identified adults living between 375 m and 1400 m from the nearest wind turbine when compared to a group of 41 participants living between 3.3 km and 6.6 km away. For the same reasons outlined above concerning Shepherd et al. (2011), it is difficult to compare the findings from the current study to those reported by Nissenbaum et al. (2012). Additionally, a different QOL instrument, the SF-36®, was used in the Nissenbaum et al. (2012) study. The SF-36®, also used in a Polish wind turbine study by Mroczek et al. (2012), is a valuable tool in assessing health and functional status. However, the SF-36® does not examine perceptions of health and well-being to the same degree as the WHOQOL-BREF, nor does it include satisfaction with the living environment and neighbourhood (Asnani et al., 2009; Cruice et al., 2000). The inclusion of

Table 2d
Multiple linear regression model: Environment domain.

Variable	Groups in variable	LSM (95%CI) (R^2=0.24, n=985)	PWC	p-Value
WTN levels (dB)	< 25 (n=84)	16.28 (15.58, 16.98)		0.3681
	25– < 30 (n=95)	15.71 (14.99, 16.44)		
	30– < 35 (n=304)	15.75 (15.16, 16.34)		
	35– < 40 (n=521)	15.82 (15.28, 16.36)		
	40–46 (n=234)	15.73 (15.17, 16.28)		
Province	PEI (n=227)	15.76 (15.15, 16.36)		0.2759
	ON (n=1011)	15.96 (15.45, 16.47)		
Personal benefit from having wind turbines in the area	Yes (n=110)	15.92 (15.26, 16.57)		0.6324
	No (n=1075)	15.80 (15.31, 16.29)		
Age group	≤ 24 (n=72)	16.34 (15.56, 17.12)	A	< 0.0001
	25-44 (n=331)	15.45 (14.90, 16.00)	B	
	45-64 (n=547)	15.42 (14.89, 15.95)	B	
	65+ (n=288)	16.22 (15.63, 16.82)	A	
Level of education	≤ High school (n=678)	15.60 (15.06, 16.14)	A	0.0228
	Trade/certificate/college (n=469)	15.67 (15.13, 16.21)	A	
	University (n=90)	16.31 (15.63, 16.99)	B	
Income	< 60k (n=531)	15.33 (14.78, 15.89)	A	< 0.0001
	60–100k (n=300)	15.95 (15.37, 16.52)	B	
	≥ 100k (n=220)	16.29 (15.72, 16.87)	B	
Property ownership	Own (n=1076)	16.05 (15.52, 16.58)		0.0591
	Rent (n=162)	15.66 (15.06, 16.27)		
Façade type	Fully bricked (n=340)	16.09 (15.53, 16.64)		0.0790
	Partially bricked (n=218)	15.74 (15.12, 16.35)		
	No brick/other (n=680)	15.75 (15.21, 16.30)		
Number of years hearing the wind turbines	Do not hear wind turbines (n=651)	15.89 (15.38, 16.39)		0.0731
	Less than 1 year (n=61)	16.10 (15.35, 16.86)		
	1 year or more (n=522)	15.59 (15.05, 16.12)		
Visual annoyance to turbines	High (n=159)	15.58 (14.97, 16.18)		0.0096
	Low (n=1075)	16.14 (15.60, 16.68)		
Turbine shadow flicker annoyance	High (n=96)	16.08 (15.43, 16.73)		0.0916
	Low (n=1137)	15.64 (15.11, 16.16)		

Table 2d (*continued*)

Variable	Groups in variable	LSM (95%CI) (R^2=0.24, n=985)	PWC	p-Value
Alcohol use	Do not drink alcohol (n=274)	15.79 (15.22, 16.37)		0.0690
	≤ 3 Times per month (n=474)	15.73 (15.19, 16.28)		
	1–3 Times/week (n=325)	16.14 (15.56, 16.72)		
	≥ 4 Times/week (n=164)	15.77 (15.15, 16.39)		
Smoking status	Current (n=284)	15.56 (14.98, 16.13)	A	0.0134
	Former (n=423)	15.95 (15.39, 16.51)	AB	
	Never (n=531)	16.07 (15.51, 16.62)	B	
Migraines	Yes (n=289)	15.68 (15.12, 16.24)	A	0.0354
	No (n=948)	16.04 (15.49, 16.59)	B	
Dizziness	Yes (n=273)	15.58 (15.01, 16.15)	A	0.0013
	No (n=965)	16.14 (15.59, 16.69)	B	
Tinnitus	Yes (n=293)	15.65 (15.09, 16.21)	A	0.0132
	No (n=944)	16.06 (15.51, 16.62)	B	
Chronic pain	Yes (n=293)	15.60 (15.04, 16.16)	A	0.0013
	No (n=943)	16.12 (15.57, 16.66)	B	
Asthma	Yes (n=101)	15.61 (14.96, 16.25)	A	0.0373
	No (n=1137)	16.11 (15.60, 16.62)	B	
Diagnosed sleep disorder	Yes (n=119)	15.51 (14.89, 16.14)	A	0.0020
	No (n=1119)	16.20 (15.68, 16.73)	B	

environmental and neighbourhood satisfaction would seem to be particularly relevant in the context of wind turbines and how they may impact QOL. Although there is some evidence that indicates the WHOQOL-BREF and SF-36® are comparable in measuring QOL among different clinical populations (Asnani et al., 2009; Hsiung et al., 2005), it is not clear whether this would also apply to communities living within the vicinity of wind turbine installations.

In contrast to Nissenbaum et al. (2012), Mroczek et al. (2012) reported significantly improved QOL on all eight scales of the SF-36® among a Polish population of 220 individuals living within 700 m of a wind farm compared to the 424 individuals living beyond 1500 m. Mroczek et al. (2012) noted that some individuals received economic benefit associated with wind turbines, however this variable was not included in their analysis. Furthermore, Mroczek et al. (2012) concluded that close proximity to wind farms did not result in worsening of QOL, and suggested future research include questions about economic benefit from both land rental for wind farm construction and possible employment in the wind industry.

The influence that economic benefit may have on QOL is uncertain. Receiving personal benefit, when analysed alone, was related to all 4 WHOQOL-BREF domains as well as QOL and Satisfaction with Health stand-alone questions. However, when other variables were also considered in the multiple regression models the relationships changed and personal benefit was only found to be (marginally) related to the Physical Health domain (p=0.0415). This finding was independent of WTN exposure. In relation to personal benefit, a similar finding was reported by van den Berg et al. (2008), who

Table 3a
Multiple logistic regression model: QOL rating.

Variable	Groups in variable[a,b]	QOL rating[c] OR (CI)[d]	QOL rating[c] p-Value[e]
		(n=946, R^2=0.31, H–L p=0.6796)[f]	
Intercept			0.0001
WTN levels (dB)[g]		1.02 (0.80, 1.32)	0.8523
Province	ON/PEI (n=1011, n=227)	0.66 (0.30, 1.45)	0.3030
Personal benefit[h]	No/yes (n=1075, n=110)	2.51 (0.55, 11.54)	0.2361
Marital status	Married/common-law (n=848)	0.40 (0.18, 0.91)	0.0293
	Widowed/separated/divorced (n=215)	0.37 (0.14, 0.98)	0.0444
	Single, never been married (n=172)	Reference	
Employment	Yes/no (n=722, n=515)	0.56 (0.31, 1.01)	0.0521
Sensitivity to noise	High/low (n=175, n=1059)	1.90 (1.00, 3.62)	0.0516
Dizziness	Yes/no (n=273, n=965)	3.34 (1.88, 5.95)	< 0.0001
Chronic pain	Yes/no (n=293, n=943)	3.43 (1.93, 6.09)	< 0.0001
Asthma	Yes/no (n=101, n=1137)	3.72 (1.76, 7.86)	0.0006
High blood pressure	Yes/no (n=372, n=862)	3.06 (1.69, 5.55)	0.0002
Heart disease	Yes/no (n=95, n=1142)	0.42 (0.15, 1.16)	0.0927
Diagnosed sleep disorder	Yes/no (n=119, n=1119)	4.56 (2.33, 8.94)	< 0.0001

CI, confidence interval; dB, decibel; H–L, Hosmer–Lemeshow; ON, Ontario; OR, odds ratio; PEI, Prince Edward Island; QOL, quality of life; WTN, wind turbine noise.

[a] The sample size for each variable does not always sum to the study sample size (n=1238) as not all participants responded to each question.

[b] Where a reference group is not specified it is taken to be the last group.

[c] The multiple logistic regression is modeling the probability of a respondent as rating their quality of life as "Poor" which includes those that responded "Poor" and "Very Poor".

[d] OR (CI) odds ratio and 95% confidence interval based on multiple logistic regression model. An OR < 1 implies that the category has lower odds of rating QOL as "poor" compared to the reference category.

[e] p-Value significance is in relation to the reference group.

[f] H–L: Hosmer–Lemeshow test, $p > 0.05$ indicates a good fit.

[g] WTN level is treated as a continuous scale in the logistic regression model, giving an overall slope and OR for each unit increase in WTN level, where a unit reflects a 5 dB WTN category.

[h] Personal benefit (i.e., rent, payments or other indirect benefits through community improvements) from having wind turbines in the area.

Table 3b
Multiple logistic regression model: Satisfaction with Health

Variable	Groups in variable[a,b]	Satisfaction with Health[c] OR (CI)[d]	Satisfaction with Health[c] p-Value[e]
		(n=989, R^2=0.29, H–L p=0.9214)[f]	
Intercept			< 0.0001
WTN levels (dB)[g]		0.99 (0.82, 1.18)	0.8726
Province	ON/PEI (n=1011, n=227)	0.94 (0.54, 1.64)	0.8243
Personal benefit[h]	No/yes (n=1075, n=110)	1.21 (0.52, 2.82)	0.6544
Alcohol consumption	Do not drink alcohol (n=274)	Reference	
	≤ 3 Times/month (n=474)	1.10 (0.68, 1.78)	0.7067
	1–3 Times/week (n=325)	0.50 (0.28, 0.90)	0.0202
	≥ 4 Times/week (n=164)	0.34 (0.16, 0.74)	0.0062
Hear aircraft	Yes/no (n=609, n=629)	0.54 (0.36, 0.82)	0.0036
Sensitivity to noise	High/low (n=175, n=1059)	1.55 (0.94, 2.53)	0.0834
Migraines[i]	Yes/no (n=289, n=948)	1.60 (1.00, 2.57)	0.0491
Dizziness	Yes/no (n=273, n=965)	2.07 (1.31, 3.26)	0.0017
Chronic pain	Yes/no (n=293, n=943)	3.92 (2.49, 6.18)	< 0.0001
Arthritis	Yes/no (n=402, n=835)	1.65 (1.06, 2.57)	0.0281
Diabetes	Yes/no (n=113, n=1123)	1.72 (0.94, 3.18)	0.0811
Heart disease	Yes/no (n=95, n=1142)	1.74 (0.91, 3.31)	0.0939
Diagnosed sleep disorder	Yes/no (n=119, n=1119)	2.62 (1.52, 4.52)	0.0005

CI, confidence interval; dB, decibel; H–L, Hosmer–Lemeshow; ON, Ontario; OR, odds ratio; PEI, Prince Edward Island; QOL, quality of life; WTN, wind turbine noise.

[a] The sample size for each variable does not always sum to the study sample size (n=1238) as not all participants responded to each question.

[b] Where a reference group is not specified it is taken to be the last group.

[c] The multiple logistic regression is modeling the probability of a respondent as rating their satisfaction with health as "Dissatisfied" which includes those that responded "Dissatisfied" and "Very Dissatisfied".

[d] OR (CI) odds ratio and 95% confidence interval based on multiple logistic regression model. An OR < 1 implies that the category has lower odds of rating QOL as "poor" compared to the reference category.

[e] p-Value significance is in relation to the reference group.

[f] H–L: Hosmer–Lemeshow test, $p > 0.05$ indicates a good fit.

[g] WTN level is treated as a continuous scale in the logistic regression model, giving an overall slope and OR for each unit increase in WTN level, where a unit reflects a 5 dB WTN category.

[h] Personal benefit (i.e., rent, payments or other indirect benefits through community improvements) from having wind turbines in the area.

[i] Migraines or headaches (including nausea, vomiting, sensitivity to light and sound).

Table 4
Summary of variables retained in multiple regression models for WHOQOL-BREF

	Domains				Stand-alone questions	
	Physical	Psychological	Social Relationships	Environment	Rated QOL as *poor*	Rated Satisfaction with Health as *dissatisfied*
Demographic variables						
Province		X				
Sex			X			
Age group		X	X	X		
Marital status	X	X	X		x	
Employment	X	X	X		x	
Smoking status	X			X		
Level of education		X		X		
Income				X		
Alcohol use	X	x		x		X
Property ownership				x		
Façade type			X	x		
Audible aircraft						X
Audible rail	x		x			
Wind turbine related variables						
Number of years turbines audible		X		x		
Personal benefit	X					x
Visual annoyance	X			X		
Shadow flicker annoyance				x		
Personal and health-related variables						
Sensitivity to noise		x			x	x
Migraines		X	X	X		X
Dizziness	X	X	X	X	X	X
Chronic pain	X	X	X	X	X	X
Diagnosed sleep disorder	X	X	X	X	X	X
Tinnitus	X	X		X		
Arthritis	X					X
High blood pressure					X	
Medication for high blood pressure	X					
Chronic bronchitis/emphysema/COPD	X		X			
Diabetes	X	x				x
Heart disease					x	x
Asthma				X	X	

All variables marked in the table were statistically significant at $p < 0.10$, variables marked with an upper case X are statistically significant at $p < 0.05$. WHO, World Health Organization; QOL, quality of life. Rated QOL as "Poor" includes participants that responded "Poor" and "Very Poor"; Rating Satisfaction with Health as "Dissatisfied" includes participants that responded "Dissatisfied" or "Very Dissatisfied".

concluded that '*those benefiting are more usually 'healthy farmers', have a more positive view on the visual impact of wind turbines and are relatively young and well educated*'.

Although exposure to WTN was not found to be related to the 4 domains or the QOL or Satisfaction with Health questions, there were specific wind turbine-related variables, beyond personal benefit, that did have an influence on some of these outcomes and which were retained in the multiple regression models. Reporting high visual annoyance from wind turbines was found to be related to lower scores on both the Physical Health and Environment domains of the WHOQOL-BREF, but was unrelated to Psychological, Social Relationships, or rated QOL or Satisfaction with Health. The link between high visual annoyance and lower Environment domain scores is not unexpected as this domain taps into the level of satisfaction respondents report with their physical living space and how healthy and safe they believe their physical environment to be (WHOQOL-BREF, 1996). It is therefore not unreasonable that the Environment domain score would be sensitive to one's annoyance towards the visual presence of wind turbines. In terms of the Physical Health domain, it could be speculated that a high visual annoyance with wind turbines may influence one or more of the facets which comprise this particular domain. It is also possible that the visual perception of wind turbines may have an influence on the perception of the sound levels produced by wind turbines. Visual attributes were found to have an influence on the auditory perception of wind turbines in a controlled laboratory study by Maffei et al. (2013) and may extend to field settings. Although this study represents a relatively new area of investigation, the findings of this study add to existing research that have reported visual disturbance from wind turbines or negative attitudes towards the visual impact of wind turbines on the landscape (Blackburn et al., 2009; Devine-Wright and Howes, 2010; Pasqualetti, 2011; Pedersen and Larsman, 2008; Pedersen and Persson Waye, 2007).

The CNHS study included questions to investigate the length of time respondents reported that wind turbines were audible as a proxy for their history of exposure to WTN. The rationale was to provide insight into whether individuals were adapting or becoming sensitized to WTN exposure over time. Comparisons between participants not hearing wind turbines at all and those who reported hearing them for less than or greater than or equal to 1 year, revealed that those who reported to have heard WTN for less than 1 year had slightly higher (i.e. mean difference between 0.78 and 1.0) scores on the Psychological domain, relative to the absent and greater than or equal to 1 year categories. The small changes between groups, the inconsistent pattern of response with extended audibility and the lack of longer term follow-up make it impossible to draw any meaningful conclusions from these results.

With respect to noise sensitivity, 14% of the respondents indicated that they were either very or extremely (i.e. highly) sensitive to noise in general, which is in line with the prevalence rates of 12% and 15% reported in previous studies (Miedema and Vos, 2003; van Kamp et al., 2004). In the univariate analysis, noise sensitivity was found to be significantly associated with Physical Health, Social Relationships, and Environment domains and marginally with the Psychological domain. In all cases, being highly noise sensitive was related to a worsening of QOL in these areas. Similarly, the odds of reporting poor QOL and Dissatisfaction with Health were higher among those who were highly noise sensitive. However, when considered along with other factors in multiple regression models for the different domains and two stand-alone WHOQOL-BREF questions, noise sensitivity becomes less relevant. This suggests that other factors, which included, but were not limited to, having chronic pain or a chronic disease, being unemployed and suffering from migraines, were more important in explaining the overall variance in the final models.

5. Conclusions

In the current study, the overall variance accounted for in the multiple regression models pertaining to the 4 WHOQOL-BREF domains was between 16% and 45%. The models for the two stand-alone questions, rated QOL and Satisfaction with Health, were also rather weak at 31% and 29%, respectively. These findings demonstrate that most of the variance in these models cannot be accounted for by the variables included in the current study. Many of the demographic and health-related variables previously shown to be related to QOL were statistically related to multiple QOL parameters assessed using the WHOQOL-BREF questionnaire. This demonstrates that the utilization of this tool in the current study was a sensitive measure for detecting changes in QOL. Therefore, it is notable that WTN levels up to 46 dB were not statistically related to any of the modeled outcomes.

The current study modeled WTN levels using a long term A-weighted metric, however it may be that a noise metric other than, or in addition to the A-weighting may reveal a stronger association with self-reported QOL. In the current study, C-weighted WTN levels were modeled in addition to A-weighted levels, however these results were not presented as the dBC and dBA values were highly correlated (Michaud, 2015). A large-scale wind turbine epidemiological/laboratory study conducted in Japan considered A- C- and G-weighted WTN levels, in addition to amplitude modulation, and concluded that the response to wind turbines was more accurately assessed using the A-weighted metric (Tachibana et al., 2014). However, they concluded that a quantification of amplitude modulation and tonality was warranted in future wind turbine studies, a conclusion echoed in a key finding of the Council of Canadian Academies (2015) following their review of the wind turbine literature. Therefore, a quantification of these sound characteristics may provide further insight into how WTN exposure may influence QOL.

Acknowledgements

The authors acknowledge the support they received throughout the study from Serge Legault and Suki Abeysekera at Statistics Canada, and are especially grateful to the volunteers who participated in this study.

Appendix A. Supplementary material

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.envres.2015.06.043.

References

Agresti, A., 2002. Categorical Data Analysis, 2nd edition. Wiley & Sons, Inc., New York.
Asnani, M.R., Lipps, G.E., Reid, M.E., 2009. Utility of WHOQOL-BREF in measuring quality of life in Sickle Cell Disease. Health Qual. Life Outcomes 7, 75. http://dx.doi.org/10.1186/1477-7525-7-75.
Blackburn, D., Rodrigue, L., Tardiff, I., Chagnon, M., Martel, K., Morasse, A., Pouliot, B., 2009. Éoliennes et santpublique. Synthèse des connaissances. Institut National de Sant Publique de Qubec, Qubec.
Bolton, R., 2007. Evaluation of Environmental Shadow Flicker Analysis for Dutch Hill Wind Power Project. Environmental Compliance Alliance, New York. Available at: 〈http://docs.wind-watch.org/shadow.pdf〉.
Bowling, A., 1995. The concept of quality of life in relation to health. Med. Secoli 7 (3), 633–645.
Chapman, S., St. George, A., Waller, K., Cakic, V., 2013. The pattern of complaints about Australian wind farms does not match the establishment and distribution of turbines: support for the psychogenic, 'communicated disease' hypothesis. PLoS One 8 (10), e76584. http://dx.doi.org/10.1371/journal.pone.0076584 (eCollection 2013).
Chief Medical Officer of Health Ontario, 2010. The Potential Health Impact of Wind Turbines. Chief Medical Officer of Health (CMOH) Report. Queen's Printer for Ontario Toronto, ON, pp. 1–14. Available at: 〈http://www.health.gov.on.ca/en/common/ministry/publications/reports/wind_turbine/wind_turbine.pdf〉.
Council of Canadian Academies, 2015. Understanding the Evidence: Wind Turbine Noise. The Expert Panel on Wind Turbine Noise and Human Health. Council of Canadian Academies, Ottawa, Ontario. Available at: 〈http://www.scienceadvice.ca/uploads/eng/assessments%20and%20publications%20and%20news%20releases/wind-turbine-noise/WindTurbineNoiseFullReportEn.pdf〉.
Crichton, F., Dodd, G., Schmid, G., Gamble, G., Cundy, T., Petrie, K.J., 2014. The power of positive and negative expectations to influence reported symptoms and mood during exposure to wind farm sound. Health Psychol. 33 (12), 1588–1592. http://dx.doi.org/10.1037/hea0000037 (Epub 2013 Nov 25).
Cruice, M., Hirsch, F., Worrall, L., Holland, A., Hickson, L., 2000. Quality of life for people with aphasia: Performance on and usability of quality of life assessments. Asia Pac. J. Speech Lang. Hear. 5, 85–91. http://dx.doi.org/10.1179/136132800805577040.
DataKustik GmbH®, 2014. Software for Immission Protection. Available at: www.datakustik.com (Accessed 24.11.14).
Department of Energy and Climate Change, 2011. Update of UK Shadow Flicker Evidence Base: Final Report. Parsons Brinckerhoff, London, UK. Available at: 〈https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/48052/1416-update-uk-shadow-flicker-evidence-base.pdf〉.
Devine-Wright, P., Howes, Y., 2010. Disruption to place attachment and the protection of restorative environments: a wind energy case study. J. Environ. Psychol. 30 (3), 271–280. http://dx.doi.org/10.1016/j.jenvp.2010.01.008.
Guite, H.F., Clark, C., Ackrill, G., 2006. The impact of the physical and urban environment on mental well-being. Public Health 120, 1117–1126.
Harding, G., Harding, P., Wilkins, A., 2008. Wind turbines, flicker, and photosensitive epilepsy: characterizing the flashing that may precipitate seizures and optimizing guidelines to prevent them. Epilepsia 49 (6), 1095–1098. http://dx.doi.org/10.1111/j.1528-1167.2008.01563.x (Epub 2008 Apr 4).
Harrison, M.B., Juniper, E.F., Mitchell-DiCenso, A., 1996. Quality of life as an outcome measure in nursing research: "May you have a long and healthy life". Can. J. Nurs. Res. 28 (3), 49–68.
Henningsen, P., Priebe, S., 2003. New environmental illnesses: What are their characteristics? Psychother. Psychosom. 72 (5), 231–234.
Hsiung, P.C., Fang, C.T., Chang, Y.Y., Chen, M.Y., Wang, J.D., 2005. Comparison of WHOQOL-BREF and SF-36 in patients with HIV infection. Qual. Life Res. 14 (1), 141–150.
Hutchinson, G., Simeon, D.T., Bain, B.C., Wyatt, G.E., Tucker, M.B., Lefranc, E., 2004. Social and health determinants of well being and life satisfaction in Jamaica. Int. J. Soc. Psychiatry 50 (1), 43–53.
ISO, 1993. ISO-9613-1-Acoustics. Attenuation of Sound During Propagation Outdoors. Part 1: Calculation of the Absorption of Sound by the Atmosphere. International Organization for Standardization, Geneva.
ISO, 1996. ISO 9613-2-Acoustics. Attenuation of Sound During Propagation Outdoors. Part 2: General Method of Calculation. International Organization for Standardization, Geneva.
Kalfoss, M.H., Low, G., Molzahn, A.E., 2008. The suitability of the WHOQOL-BREF for Canadian and Norwegian older adults. Eur. J. Ageing 5, 77–89. http://dx.doi.org/10.1007/s10433-008-0070-z.
Katsaprakakis, D.A., 2012. A review of the environmental and human impacts from wind parks. A case study for the Prefecture of Lasithi, Crete. Renew. Sustain. Energy Rev. 16 (5), 2850–2863. http://dx.doi.org/10.1016/j.rser.2012.02.041.
Knopper, L.D., Ollson, C.A., McCallum, L.C., Whitfield Aslund, M.L., Berger, R.G., Souweine, K., McDaniel, M., 2014. Wind turbines and human health. Front. Public Health 2 (63), 1–20. http://dx.doi.org/10.3389/fpubh.2014.00063.
Maffei, L., Iachini, T., Masullo, M., Aletta, F., Sorrentino, F., Senese, V.P., Ruotolo, F., 2013. The effects of vision-related aspects on noise perception of wind turbines in quiet areas. Int. J. Environ. Res. Pub. Health 10 (5), 1681–1697. http://dx.doi.org/10.3390/ijerph10051681.
Massachusetts Department of Environmental Protection (MassDEP) and Massachusetts Department of Public Health (MDPH). 2012. Wind Turbine Health Impact Study: Report on Independent Expert Panel. Department of

Environmental Protection and Department of Public Health. Available at: ⟨http://www.mass.gov/eea/docs/dep/energy/wind/turbine-impact-study.pdf⟩ (Accessed 15.05.15).
Merlin, T., Newton, S., Ellery, B., Milverton, J., Farah, C., 2014. Systematic Review of the Human Health Effects of Wind Farms. National Health and Medical Research Council, Canberra ACT. Available at: ⟨https://digital.library.adelaide.edu.au/dspace/handle/2440/87923⟩.
McIver, J.P., Carmines, E.G., 1981. Unidimensional Scaling. Sage, Thousand Oaks, CA.
Michaud, D.S., Keith, S.E., Feder, K., Soukhovtsev, V., Marro, L., Denning, A., McGuire, D., Broner, N., Richarz, W., Tsang, J., Legault, S., Poulin, D., Bryan, S., Duddeck, C., Lavigne, E., Villeneuve, P.J., Leroux, T., Weiss, S.K., Murray, B.J., Bower, T., 2013. Self-reported and objectively measured health indicators among a sample of Canadians living within the vicinity of industrial wind turbines: social survey and sound level modelling methodology. Noise News Int. 21, 14–27.
Michaud D.S. (2015) Self-reported and objectively measured outcomes assessed in the Health Canada wind turbine noise and health study: Results support an increase in community annoyance, Internoise, San Francisco, California, USA, August 9-12, 2015.
Miedema, H.M., Vos, H., 2003. Noise sensitivity and reactions to noise and other environmental conditions. J. Acoust. Soc. Am. 113 (3), 1492–1504. http://dx.doi.org/10.1121/1.1547437.
Molzahn, A.E., Pagé, G., 2006. Field testing the WHOQOL-100 in Canada. Can. J. Nurs. Res 38 (3), 106–123.
Mroczek, B., Kurpas, D., Karakiewicz, B., 2012. Influence of distances between places of residence and wind farms on the quality of life in nearby areas. Ann. Agric. Environ. Med. 19 (4), 692–696.
Mroczek, B., Banaś, J., Machowska-Szewczyk, M., Kurpas, D., 2015. Evaluation of quality of life of those living near a wind farm. Int. J. Environ. Res. Public Health 12, 6066–6083. http://dx.doi.org/10.3390/ijerph120606066.
Nissenbaum, M.A., Aramini, J.J., Hanning, C.D., 2012. Effects of industrial wind turbine noise on sleep and health. Noise Health 14 (60), 237–243. http://dx.doi.org/10.4103/1463-1741.102961.
Nunnally, J.C., Bernstein, I.H., 1994. Psychometric Theory, 3rd ed. McGraw-Hill, New York.
Onakpoya, I.J., O'Sullivan, J., Thompson, M.J., Heneghan, C.J., 2014. The effect of wind turbine noise on sleep and quality of life: a systematic review and meta-analysis of observational studies. Env. Int. 82, 1–9.
Oregon Health Authority, 2013. Strategic Health Impact Assessment on Wind Energy Development in Oregon. Office of Environmental Public Health Public Health Division, Salem Oregon. Available at: ⟨https://public.health.oregon.gov/HealthyEnvironments/TrackingAssessment/HealthImpactAssessment/Documents/Wnd%20Energy%20HIA/Wind%20HIA_Final.pdf⟩.
Pasqualetti, M.J., 2011. Opposing wind energy landscapes: a search for common cause. Ann. Assoc. Am. Geog. 101 (4), 907–917. Available at: ⟨http://climateshiftproject.org/wp-content/uploads/2013/04/Pasqualetti2011_OpposingWindEnergyCommonCauses_AnnalsGeogy.pdf⟩.
Pedersen, E., Persson Waye, K., 2007. Wind turbine noise, annoyance and self-reported health and wellbeing in different living environments. Occup. Environ. Med. 64, 480–486.
Pedersen, E., Larsman, P., 2008. The impact of visual factors on noise annoyance among people living in the vicinity of wind turbines. J. Environ. Psychol. 28, 379–389. http://dx.doi.org/10.1016/j.jenvp.2008.02.009.
Pedersen, E., van den Berg, F., Bakker, R., Bouma, J., 2009. Response to noise from modern wind farms in The Netherlands. J. Acoust. Soc. Am. 126 (2), 634–643. http://dx.doi.org/10.1121/1.3160293.
Pohl, J., Faul, F., Mausfeld, R., 1999. Belastigung durch periodischen Schattenwurf von Windenergieanlagen [Annoyance Caused by Periodical Shadow-Casting of Wind Turbines]. Institut fur Psychologie Christian-Albrechts-Universität zu Kiel, Kiel, pp. 1–83. ⟨http://cvi.se/uploads/pdf/Kunskapsdatabas%20miljo/Ljud%20och%20Skuggor/Skuggor/Utredningar/Feldstudie.pdf⟩ (Accessed 15.05.15).
Pohl, J., Faul, F., Mausfeld, R., 2000. Belastigung durch periodischen Schattenwurf von Windenergieanlagen: Ergebnisseeiner Feldstudie und einer Laborpilotstudie [Annoyance Caused by Periodical Shadow- Casting of Wind Turbines: Results of a Field Study and A Laboratory Pilot Study]. Institut fur Psychologie Christian-Albrechts-Universität zu Kiel, Kiel, pp. 11–18. ⟨http://cvi.se/uploads/pdf/Kunskapsdatabas%20miljo/Ljud%20och%20Skuggor/Skuggor/Utredningar/Laborstudie%20Schattenwurf.pdf⟩ (Accessed15.05.15).
Pohl, J., Hubner, G., Mohs, A., 2012. Acceptance and stress effects of aircraft obstruction markings of wind turbines. Energy Policy 50, 592–600. http://dx.doi.org/10.1016/j.enpol.2012.07.062.
Rubin, G.J., Burns, M., Wessely, S., 2014. Possible psychological mechanisms for "wind turbine syndrome". On the windmills of your mind. Noise Health 16 (69), 116–122. http://dx.doi.org/10.4103/1463-1741.132099.
Saidur, R., Rahim, N., Islam, M., Solangi, K., 2011. Environmental impact of wind energy. Renew. Sustain. Energy Rev. 15 (5), 2423–2430. http://dx.doi.org/10.1016/j.rser.2011.02.024.
Schmidt, J.H., Klokker, M., 2014. Health effects related to wind turbine noise exposure: a systematic review. PLoS One 9 (12), e114183. http://dx.doi.org/10.1371/journal.pone.0114183.
Shepherd, D., Welch, D., Dirks, K.N., Matthews, R., 2010. Exploring the relationship between noise sensitivity and health-related quality of life in a sample of adults exposed to environmental noise. Int. J. Environ. Res. Public Health 7 (54), 3579–3594. http://dx.doi.org/10.3390/ijerph7103580.
Shepherd, D., McBride, D., Welch, D., Dirks, K.N., Hill, E.M., 2011. Evaluating the impact of wind turbine noise on health-related quality of life. Noise Health 13 (54), 333–339. Available from: ⟨http://www.noiseandhealth.org/text.asp?2011/13/54/333/85502⟩.
Silva, J., de Keulenaer, F., Johnstone, N., 2012. Environmental Quality and Life Satisfaction: Evidence Based on Micro-Data. OECD Environment Working Papers, No. 44. OECD Publishing, http://dx.doi.org/10.1787/19970900.
Skevington, S.M., Sartorius, N., Amir, M., WHOQOL Group, 2004. Developing methods for assigning quality of life in different cultural settings: the history of the WHOQOL instruments. Soc. Psychiatry Psychiatr. Epidemiol. 39, 1–8.
Smedley, A.R., Webb, A.R., Wilkins, A.J., 2010. Potential of wind turbines to elicit seizures under various meteorological conditions. Epilepsia 51 (7), 1146–1151. http://dx.doi.org/10.1111/j.1528-1167.2009.02402.x.
Spector, P., 1992. Summated Rating Scale Construction. Sage, Thousand Oaks, CA.
Stokes, M.E., Davis, C.S., Koch, G.G., 2000. Categorical Data Analysis Using the SAS System, second edition. SAS Institute Inc., Cary, NC.
Tachibana, H., Yano, H., Fukushima, A., Shinichi, S., 2014. Nationwide field measurement of wind turbine noise in Japan. Noise Control Eng. J. 62 (2), 90–101. http://dx.doi.org/10.3397/1/376209.
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. Diff. 54, 338–343. http://dx.doi.org/10.1016/j.paid.2012.09.018.
van den Berg, F., Pedersen, E., Bouma, J., Bakker, R., 2008. WINDFARM Perception: Visual and Acoustic Impact of Wind Turbine Farms on Residents. Final Report. University of Groningen. Available at: ⟨http://cordis.europa.eu/documents/documentlibrary/124729401EN6.pdf⟩.
van Kamp, I., Job, R.F., Hatfield, J., Haines, M., Stellato, R.K., Stansfeld, S.A., 2004. The role of noise sensitivity in the noise–response relation: a comparison of three international airport studies. J. Acoust. Soc. Am. 116 (6), 3471–3479.
Welch, D., Shepherd, D., Dirks, K.N., McBride, D., Marsh, S., 2013. Road traffic noise and health-related quality of life: a cross-sectional study. Noise Health 15 (65), 224–230. Available at: ⟨http://www.noiseandhealth.org/text.asp?2013/15/65/224/113513⟩.
World Health Organization (WHO), 1996. WHOQOL-BREF: Introduction, Administration, Scoring and Generic Version of the Assessment: Field Trial Version. World Health Organization, Geneva. Available at: ⟨http://www.who.int/mental_health/media/en/76.pdf⟩.
World Health Organization Quality Of Life (WHOQOL) Group, 1994. Development of the WHOQOL: rationale and current status. Int. J. Ment. Health 23 (3), 24–56.
WHOQOL Group, 1998. Development of the World Health Organization WHOQOL-BREF quality of life assessment. Psychol. Med. 28, 551–558.