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[a]

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INTRODUCTION

In Canada, all levels of government share jurisdiction for regulating sound that could be harmful to Canadians. The location of wind turbines and associated sound level limits fall under the jurisdiction of provincial governments. As of October 2013, Canada's installed capacity has surpassed 7 Gigawatts (Canadian Wind Energy Association, 2013). At the same time there is public concern for potential health impacts, which include disrupted sleep from exposure to wind turbine sound (WTS). The possible association between WTS and impairments in sleep quality has been reported in the peer reviewed literature (Pedersen and Waye, 2004; Pedersen et al., 2009; Shepherd, 2011; Nissenbaum et al., 2012). However, these studies have relied exclusively upon self-reporting as a means of assessing sleep and other community reactions to WTS. There is an inherent bias associated with self-reported data in environmental epidemiology studies (Moffatt, 2000; Smith-Sivertsen, 2000), which in some cases, makes it especially important to supplement these data with other measures. To date, there has been no study that has included objective measures of sleep disturbance, noise-induced stress or other biological markers to evaluate the potential effect on individuals that live near wind turbines.

Health Canada is collaborating with Statistics Canada on a cross-sectional epidemiological study to evaluate self-reported and objectively measured health indicators among individuals living within approximately 10km of an operational industrial wind turbine park. The results of the study are anticipated to be released late 2014.

This research, taken together with other studies in this area, is intended to provide decision makers with scientific evidence to support a global evidence base on which future research can be built. Collectively, these studies help inform decisions and policies on practices regarding wind turbine proposals, installations and operations in Canada.

This study has been approved by the Health Canada and Public Health Agency of Canada Review Ethics Board (Protocol #2012-0065 and #2012-0072). Additional review was carried out by the Study's

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Expert Committee[c], Health Canada's Science Advisory Board, World Health Organization (WHO)-selected advisors, and other professionals with expertise in the field of acoustics and social and direct measures surveys. The study design underwent further review subsequent to a 60 day public consultation period.

FIELD STUDY

Overall, this study is assessing the hypotheses that living in areas with higher WTS levels is associated with:

i. Impairments in sleep, as measured by actigraphy over 7 days;

ii. Increased stress, as measured by cortisol concentrations in hair;

iii. Elevated average systolic/diastolic blood pressure and heart rate;

iv. Elevated indoor and outdoor self-reported annoyance; and

v. Impairments in self-reported measures of perceived stress, quality of life and sleep quality.

Identification of participating households

The study locations are selected primarily based upon population density near operational industrial wind turbine installations.

Using available maps and/or environmental assessments for wind turbine projects, rough estimates of WTS level contours are delineated for the purpose of identifying potential dwellings. This approach results in a total sample of 2007 dwellings from Ontario and Prince Edward Island.

Data collection

Data collection, through personal visits involving a questionnaire and three objectively measured health indicators, is carried out simultaneously in both provinces and identified communities by 18 Statistics Canada interviewers. All homes within 600m of a wind turbine are identified for recruitment with random sampling procedures applied to all remaining dwellings up to a distance of 10

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km away from the wind turbine.

Upon confirmation of the number and ages of all people residing in the home and in order to mitigate the risk of self-selection bias, a computer assisted random selection method is applied to select one eligible individual per household between the ages of 18-79 who is then asked to participate in a personal interview, i.e. questionnaire, and physical measures collection. The informed consent procedure allows any individual to participate in the questionnaire, but decline to take part in any of the three physical measures. However, in order to participate in the physical measures collection the individual must have completed the questionnaire.

The timing of the survey administration is designed to capture responses across a minimum of two seasons.

Inclusion and exclusion criteria

Participation in the study requires that individuals between the ages 18 and 79 years of age provide informed consent and are able to complete the questionnaire in either English or French. Exclusion criteria for blood pressure measurements include conditions that would result in considerable discomfort on testing or preclude this measure altogether. Hair sampling requires a minimum length of 2 cm and diameter of ~ 4-5mm to acquire the required minimum analytical weight of 10mg. Sleep actigraphy requires that individuals are agreeable to wearing the device on their wrist and sleep at their home for at least three consecutive nights.

Computer assisted personal interview

A computer assisted personal interview (CAPI) is administered face-to-face in the individual's home. The questionnaire which takes an average of 45 minutes to complete had previously been qualitatively tested in French and English on a sample of 24 individuals selected from two different wind turbine installations. These individuals lived within 2km and could see the wind turbines from their homes. These pilot interviews are not included in the final study; rather, their purpose was to qualitatively test the appropriateness of the questionnaire, including the respondents' overall comprehension and willingness to complete both the questionnaire and the collection of the objectively measured health indicators. Based on the findings and recommendations from the testing, changes were made to questions, response categories and the flow of the questionnaire.

The final questionnaire consists of the following modules/content areas:

1. Personal characteristics;
2. Specific health questions and health care consultation;
3. Diagnosed chronic health conditions and medication usage;
4. Smoking, alcohol and caffeine consumption;
5. WHO's Quality of Life Questionnaire-BREF (Skevington et al., 2004);
6. Perceived Stress Scale (PSS) (Cohen and Williamson,1988);
7. Pittsburgh Sleep Quality Index (PSQI) (Buysee et al., 1989);
8. Perception of outdoor noise sources;
9. Housing environmental characteristics including residential history; and
10. Employment and work hours.

Considerations including response fatigue, that could negatively impact response rates, and a desire to reach as many individuals as possible, imposed an average total time limitation of 70-75 minutes for each interview. Given time limitations, some information, i.e. body weight and height, are self-reported and adjusted following methods described by Shields et al. (2011).

Objectively measured health indicators

Health Canada is assessing three measured health indicators that are collected from individuals participating in the survey; blood pressure/heart rate, hair cortisol (as a biomarker of stress), and sleep actigraphy data to assess sleep quality. Individuals provide written consent to participate in the collection of measured health indicators, however, they may opt out of any or all measures at any time. Measures of blood pressure and heart rate follow the standardized procedures used by the Canadian Health Measures Survey conducted by Statistics Canada (Bryan et al., 2010) with the following exceptions:

a. Interviewer remains in the room seated behind the respondent during the blood pressure testing period. The modification is necessary when taking measures in the home because it is neither practical nor appropriate for the interviewer to leave the room; and

b. A rest period of five minutes prior to blood pressure measurement is considered unnecessary because the individual is sitting for the previous 40-45 minutes while completing a questionnaire. Furthermore, since the protocol included six measures taken at one minute intervals, a five minute rest period is not needed to reduce a potential white coat effect.

Systolic and diastolic blood pressure and heart rate are measured electronically with an automated oscillometric device: the BpTRU™ BPM-100 (BpTRU™ Medical Devices Ltd., Coquitlam, British Columbia). The BpTRU™ meets the Association for the Advancement of Medical Instrumentation standard and the British Hypertension Society protocol. The interviewer ensures proper functioning of the BpTRU™ that the respondent does not speak, and maintains the appropriate positioning during the test. The BpTRU™ digital display is positioned so that the respondent cannot see the results during the test.

Sleep Measures

Actigraphy is a valid and reliable sleep assessment method according to reviews and guidelines established by the American Sleep Disorders Association (Thorpy et al., 1995). In a clinical review of the role and validity of actigraphy in sleep medicine, Sadeh (2011) highlights the limitations and strengths of these devices for evaluating sleep in different populations. Some of the advantages of actigraphy include reasonable validity and reliability in assessing sleep-wake patterns and continuous monitoring capacity 24 hours per day across several days. A limitation reported in earlier studies was in assessing insomnia; the use of actigraphy compared to polysomnography resulted in overestimates of sleep time due to the tendency for individuals with insomnia to lie in bed motionless for extended periods (Sadeh, 2011). However, more recent studies show that actigraphy is a valid tool for assessing insomnia among normal controls (Sanchez-Ortuno et al., 2010; Natale et al, 2009). Considering high night-to-night variability in sleep patterns in insomnia, it is suggested that a period of one week be used to provide reliable estimates (Van Someren, 2007), however, others report reliability with shorter times scales. A period of five days or longer is a recommended clinical practice point (Sadeh, 2011) as it reduces inherent measurement errors in actigraphy and increases reliability. According to Thorpy et al. (1995), actigraphy studies should be undertaken for a minimum of three consecutive 24-hour periods. Continuous use over seven consecutive days has therefore been selected for the present study and is well supported in the literature; considered more than adequate for evaluating sleep in a non-clinical study sample.

The Actiwatch 2 (Bio-Lynx Scientific Equipment Inc., Montreal, QC) is used to provide measures of sleep onset, total sleep time, awakenings, and sleep efficiency. Data are recorded in 1-min epochs. A small pilot study involving 24 individuals (different from those selected for qualitative questionnaire testing) was conducted to evaluate the protocol and three different actiwatch models prior to the study. The pilot study evaluated features of the three models for output quality and assessed anticipated issues associated with non-compliance. Inclusion of a complementary sleep diary was assessed as part of the pilot; however, it was not found to add value to actigraphy results and could negatively impact individual compliance. Whether or not an individual's bedroom window is left open during sleep is recorded to improve the estimate of the indoor sound level.

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Hair cortisol

The use of hair cortisol as an endpoint in the current study aims to assess the hypothesis that living in areas with higher WTS levels increases stress. When analysed against WTS levels, the average concentration of cortisol in hair provides a quantifiable measure of stress. Russell et al. (2011) documents several human studies using hair cortisol analyses as a chronic biomarker of stress. For example, a study of chronically unemployed individuals and another of healthy pregnant women report a positive association with self-reported stress using validated scales such as the PSS and hair cortisol levels (Kalra et al., 2007; Dettenborn et al., 2010).

Individuals provide a small amount of hair (described previously), for the measurement of cortisol concentrations. Hair samples are cut as close to the apex of the scalp as possible by the interviewer and taped on a section of bar-coded paper that identifies the scalp end of the hair. The sample is sent to the laboratory for enzyme-linked immunosorbent assay analysis, in accordance with procedures outlined in van Umm et al. (2008).

Before analysis, hair samples are trimmed to a length of 3-cm from the scalp end, which, on average, is a length that corresponds growth in the preceding 3 month time period. In some cases where hair length is insufficient to provide a 3-cm section, a two month reference period is used (i.e. ~ 2-cm) and accounted for in the analysis.

It is important to note that there are no clinical references available for hair cortisol so no inferences can be made regarding the clinical significance of the values obtained.

WIND TURBINE SOUND CHARACTERIZATION

This study targets 2007 potential dwellings in the vicinity of 393 wind turbines with rated electrical power output ranging from 660kw to 3MW. To be consistent with current Canadian practice for wind turbine site selection, sound exposures are based on predictive models that apply sound power level data obtained from manufacturers. As described below, data are supplemented with limited field measurements, including those in the low frequency and infrasonic range.

WTS Modelling

Modelling is considered more accurate in representing average WTS levels compared to discrete measurements, which are sensitive to fluctuating variables and do not discern between sources of sound. Outdoor sound pressure levels are predicted at receptors using both Datakustic CadnaA and EMD International AS WindPro software. This modelling includes implementations of ISO 9613, Harmonoise, and Nord2000. To include a simple model and allow comparison with other studies (Pedersen et al, 2004, 2007), outdoor sound pressure level predictions are made using a Swedish national method (Ljud från vindkraftverk, 2010). The predicted levels are checked against at least one acoustical and meteorological measurement at each survey location for each model of wind turbine to which the survey subjects are exposed.

Topography used in modelling

Topographical data are obtained from 1:50,000 scale maps of Canada with 10 m contour intervals. In each modelled location a search is made of provincial and municipal documents for more detailed information. Roads, railways, water, and large wooded areas are identified using topographic maps. Contour lines and large building area outlines are used in the calculated effects of barriers to sound. Self-reported line of site between an individual's home and wind turbines is assessed in the questionnaire and considered in the assessment of potential barriers to sound. As appropriate, Blue Marble Global Mapper software is used to convert Digital Elevation Models and other map formats into vector contour lines, road lines, building location points, building outlines, wooded area outlines, etc. This data is supplemented by satellite and aerial photographs from Google Earth to identify wind turbines, receptors and terrain features such as roughness length. Receptor locations are obtained by global positioning system measurements at each dwelling. Turbine locations are obtained from wind turbine operators, as well as visual identification of the number of wind turbines.

Meteorology used in modelling

As appropriate, inputs to the modelling software include meteorological classes based on the statistics of the meteorological data. These data are obtained from the nearest Environment Canada weather stations (located within 50 km). The Environment Canada data are obtained at 10m height and includes hourly reports of temperature, humidity, wind direction, wind speed, and cloud cover. The input of meteorological information into the modelling also considers measurements at 2, 10 and 80 m heights from a variety of sampling areas near the wind turbines in this study (see below). The land in the area is uniformly flat farmland with crops and scattered obstacles, although there are large bodies of water at varying distances and directions that influence local conditions. Along with the roughness length estimated from the topographic maps, this data is used to estimate meteorological classes. This accounts for wind and temperature gradients in the propagation calculations.

Source sound power used in modelling

The WTS power levels are used for modelling in accordance to IEC 61400-11. These spectra are extended from 50 Hz down to 6.3 Hz using at least one measurement for each identifiable wind turbine type. Differences observed between actual measurements and the manufacturers' data are considered in the overall assessment as an additional parameter to support analysis.

The A-weighted sound pressure levels at receptors due to road traffic and rail is quantified. For the larger roads and highways, traffic counts are available from provinces and municipalities. Rail traffic is estimated from traffic counts and published schedules. There are no large airports in the study area.

Indoor sound pressure levels modelled at receptors

A primary objective in the current study includes the assessment of WTS impacts on sleep. Ultimately, this relationship is largely a result of the transmission of outdoor sound to indoors, which is influenced by building construction, window type and window opening behavior[d]. In the current study indoor sound pressure levels are estimated using the outdoor to indoor level difference from ANSI S12.9-2005/Part 4 with windows partially open. The maximum outdoor to indoor level difference is assumed to be 25 dB (below 5 kHz) with windows partially opened. Sound measurements at a representative sub-sample of homes are used to complement the indoor estimates and assumptions of window opening behavior. Further refinements are made with self-reported bedroom dimensions and façade material from the questionnaire administered by Statistics Canada (see above). Taken together, the assessment of indoor sound pressure levels in the current study improves comparisons between results obtained in the current study and others.

WTS Measurements

Sound measurements are made 75m to 130m from the base of the turbines (depending on their size) to verify the available sound power level data, and to extend this data down to 6.3 Hz. Using the same instrumentation, additional sound measurements are made at distances up to5 km from the wind turbines to verify the sound propagation algorithms used for long distances.

To allow a verification of the indoor WTS exposure, the difference in level from outdoors to indoors is measured at a sample of homes. The details of the construction of each house and the participant's bedroom dimensions are documented. It is realized that other sources of sound, in addition to wind turbines, will contribute to both the outdoor and indoor sound level. Therefore, the outdoor to indoor level difference will result in an under estimate of façade sound level difference.

Source sound power and sound propagation measurements

Wind turbine sound power measurements conform as closely as possible to the requirements of IEC 61400-11; however measurements are impacted by sound from multiple wind turbines and the microphones may not always be placed according to the exact specifications in IEC 61400-11. For practical reasons related to scheduling wind turbine shutdowns, background noise is only expected to be obtained from measurements taken at a single wind speed from each measured turbine. During these measurements, wind and temperature are monitored simultaneously at 2m and 10m heights using a portable weather station. These measurements are considered with 12 months of historical meteorological data, wind turbine electrical power output, and wind turbine rpm data that is acquired from wind turbine operators. Measured data and operator data are compared to Environment Canada data for wind speed and wind direction from the nearest weather stations to check that are all synchronised to the same time and true north.

Similar measurements to those used for the determination of WTS power levels are made at distances up to 5km to support sound propagation models. The identification of WTS uses identifiable features in the measured signal, such as harmonics, amplitude modulation and unique spectral shape that are in some cases identified by turning the turbine on and off. As in the sound power measurement, to minimize the effect of wind noise on the microphone, the sound levels are measured at ground level, i.e., not at ear height. The meteorological conditions are monitored with the weather station installed at the most representative position. In these measurements an attempt is also made to use meteorology to estimate the wind induced pseudo sound at the microphone (van den Berg, 2006).

Outdoor measurements of WTS are made with Brüel & Kjær type 4189 ½ inch pre-polarized microphones with 15 dBA noise floor and -3 dB lower limiting frequency at 4 Hz. These microphones are located at ground level using, for example, a Brüel & Kjær type UA-2133 ground disk with 750 mm and 90 mm hemispherical windscreens. Data acquisition is made with Brüel & Kjær type 2250/70 sound level meter with 24 bit sampling. Measurements are also made at some homes with a Brüel & Kjær PULSE system with a LAN-XI front end having dual 24 bit input modules. As all measurements are unattended, twenty four bit Z weighted recordings are made during all outdoor data acquisition to allow detailed post analysis and quantification of noise sources (e.g., background noise).

Two different models of portable weather stations are used. Most measurements use a Sutron Xlite data logger with temperature/relative humidity sensor with AT/RH solar radiation shield (used for humidity measurement), two platinum temperature sensors with gill multi-plate solar radiation shield, barometric pressure sensor, and two Windsonic 3 ultrasonic anemometer and wind direction sensors. Data from each sensor is sampled every second. Some measurements are acquired with an Onset HOBO U30 NRC data logger with S-THB-M002 temperature humidity sensor with RS3 solar radiation shield (used for humidity measurement only), two S-TMB-M017 temperature sensor with RS3 solar radiation shield, S-BPB-CM50 barometric pressure sensor, and two S-WCA-M003 cup anemometers and direction vanes. Data from the HOBO system is sampled every 10 seconds. The weather station sensors are mounted at 2 m and 10 m height on a Clark QT 10/HP mast. In some cases leaf wetness sensors are added to assist in the identification of transient precipitation.

Infrasound measurements

Infrasound propagation is validated by measurements similar to the method used for source sound power and sound propagation. One notable difference is that data collection occurs continuously across four seasons to capture all appropriate meteorological classes over a one year period. Simultaneous measurements occur at 125m, 2km, 5km and 10km from a wind farm consisting of four 3MW wind turbines. Measurements are also made during scheduled shutdowns. Pressure is measured using micro barometers (Chaparral Physics Model 25) with a 50-foot radius, cross-shaped wind screen consisting of Yardworks 16mm O.D. household garden semi-porous soaker hose. The WTS signal has a fundamental around 0.4 to 0.9 Hz with a number of harmonics at higher frequencies. In some cases these harmonics are readily measured at distances up to 10 km and confirmed to originate from wind turbines by comparing to operational data logs. However, on many occasions, the measured signal is overwhelmed by local ambient sound.

Outdoor to indoor sound pressure level difference measurements

Measurements of the difference in sound pressure level from outdoors to indoors follow the procedures of ISO 140-5:1998 and are extended to below 50 Hz. Data are obtained in a bedroom on the WT exposed side of the dwelling. Using existing WTS these measurements are evaluated overnight, (based on the procedures in ISO 140-5, informative Annex D), in an occupied bedroom with the window opening set by the homeowners (see comment in footnote d). Similar measurements are made during the daytime using loudspeaker sound sources located outdoors (following both the global and element methods in ISO140-5:1998). These latter measurements are made with windows both closed and open.

In addition, between 16 Hz and 250 Hz a reciprocal measurement of the sound pressure level difference is made, similar to the procedure of Sharp and Martin (1996). In this measurement the loudspeaker sound source is located indoors. After suitable adjustments, this technique should produce an equivalent result to that which would be obtained with ISO140-5:1998.

To ensure adequate consideration of lower frequencies, supplementary microphone positions are added to the above measurements. These positions are 20 mm from the trihedral room corners that had the most solid construction (Hoffmeyer and Sondergaard, 2008). For the overnight measurements based on ISO140-5 Annex D, the trihedral corner is the only indoor measurement position used. Brüel & Kjær type 2250/70 sound level meters are used for data acquisition. It is necessary to make measurements simultaneously indoors and outdoors because the sound sources in these measurements are not calibrated sources. National Instruments Labview software creates the sound exposure and a Fujitsu Lifebook N computer generates the sound signal. The sound signal is reproduced through a Paradigm Signature S1 bookshelf speaker and a lightweight Paradigm Servo subwoofer with 15 inch woofer for frequencies at 160 Hz and below. The loudspeaker spectrum is shaped to give a nominal 10 dB above the background noise indoors. In hemi anechoic space at 1 m the sound levels in 1/3 octave bands will be approximately 64 dB at 16 Hz and 96 dB at 1 kHz.

STATISTICAL ANALYSIS

Exposure response models are being used in the current study to describe the relationship between modelled WTS and various endpoint measures. Dwellings are classified into: 1) modelled WTS level bins at 5 dB(A) intervals; i.e., <30, 30- <35, 35- <40, 40- <45, and ≥45; and 2) calculated distances from nearest wind turbine; i.e., <500m, 500m-750m, 751m-1000m, 1001m-5km, >5km. The study is designed to investigate different exposure levels down to negligible levels where WTS cannot be differentiated from ambient sound levels. There is an assumption in this approach that individuals living close to and far away from wind turbines are distinguished by their exposure to WTS and that other factors, including other external noise sources that may impact an individual's response, would be treated as covariates in the statistical modelling.

The outcomes of primary interest are the objectively measured health indicators and their occurrence in individuals living at varying "sound bins" or distances from wind turbines; however, they are also analyzed with respect to their relationship to self-reported measures from the questionnaire. The statistical analysis is described here to reflect the type of data that is analyzed (interval, categorical, and repeated measures) and the approach taken.

Continuous Data: These include outcomes such as cortisol levels, blood pressure, age, and scores from the World Health Organization's Quality of Life scale (ref), perceived stress scale and PSQI. An analysis of variance (ANOVA) is used to relate interval data to WTS level bins or distance groups. Assumption checks to validate the models are tested (for both the original scale and log scale of the data where the geometric mean is meaningful) using Anderson-Darling Test for normality and Levene's test for equal variance. When the assumptions are not satisfied the non-parametric Kruskal Wallis test is used. When an overall significant difference ($p<0.05$) between sound bins or distance groups exists, the Tukey pair wise test is applied in order to control the overall Type I error rate to be less than 0.05. A sensitivity analysis is conducted in order to determine the influence of outliers (very large values with a studentized residual greater than four). In cases where influential data affect the results, non-parametric results are reported.

Multiple regression models to investigate the effect for possible covariates are developed using stepwise regression models. Stepwise regression models involve searching the list of potential covariates in addition to WTS level bins (or distance group) to develop the best model to predict the outcome variable of interest. These models guard against issues of multicollinearity (covariates that are highly correlated) as well as to assess the correlation between the different variables and the outcome variable given other covariates present in the model. All variables that are significant at the 20% level are entered into the model, with a criterion of 10% significance to remain in the model. Multiple R2 along with the significance of remaining variables are used as criteria for improved fit in the model. After the addition of significant covariates are determined in the model, the interpretation of the effect of WTS bin (or distance groups) can be better understood on the outcome variable in the presence of other confounders and moderating variables. Assumptions similar to ANOVA are tested and a sensitivity analysis is conducted in order to determine influential points.

Pearson correlation coefficient is reported to look at the association between various continuous data e.g., measured cortisol concentrations and scores from the perceived stress scale and other measured indicators. Spearman correlation is used when the assumptions of bivariate normality are not satisfied and to assess the association between ordered data.

Categorical Data: These include but are not limited to the proportion of individuals in the various annoyance levels with respect to the WTS, self-reported health indicators (e.g., headaches, migraines, tinnitus and nausea), and prevalence of self-reported sleep disturbance. Prevalence rates with corresponding 95% confidence intervals as determined by Wilson (Altman et al., 2000) are reported. For analysis purposes, self-reported annoyance (for all community noise sources probed in the questionnaire) is dichotomized into two groups: highly annoyed (very and extremely annoyed) and not annoyed (not at all, slightly or moderately annoyed). A chi-square test of independence is applied to examine differences between proportions, as well as the Cochrane Armitage test to inspect trends in prevalence rates and WTS level bins (or distance groups). A logistic regression model is used to investigate difference between WTS bins (or distance group) for dichotomous response variables. Multiple logistic regression models are used to consider the effect of covariates on the dichotomous response variable of interest. The Hosmer-Lemeshow test determines the fit of the regression models to the data, whereby $p>0.05$ indicates a good fit. Where appropriate odds ratios with corresponding confidence intervals are reported.

Repeated Measures: The repeated measures in this study are derived from actigraphy. The minimum period of data acquisition is 72 consecutive hours out of the seven day measurement period. Outcome variables for these analyses include sleep latency, wake after sleep onset, total sleep time and sleep efficiency. To analyze these repeated measures a linear mixed effect model is used to relate actigraphy endpoints to WTS level bins (or distance groups). Day of measurement (the repeated factor), along with the interaction between these two effects (day of measurement and WTS level bin and distance group), are also accounted for in the model. Linear mixed effects models are applied in order to take into account the correlation between repeated measures within the same individual. The advantage of using mixed effects models is that they make use of all the available data to estimate individual subject variability and are less sensitive to missing values, which results from individuals that do not fully comply with instructions.

Multiple linear mixed effects models are developed to include potential covariates into the model to help explain the variability found in the outcome endpoints. Univariate regression models are initially fit relating various covariates to the actigraphy endpoints. Significant covariates ($p<0.20$) are then used to build a multiple regression model to best explain the variability in the outcome endpoint.

In order to eliminate the possibility of multicollinearity in the multiple regression models, correlation between covariates is assessed. Correlation between categorical covariates (or responses from the questionnaire) appearing to be measuring the same outcome are assessed using a chi-square test of independence (with continuity correction where appropriate for 2x2 frequency tables). Correlation between continuous covariates is assessed using Pearson correlation coefficient. In cases where covariates are correlated, the covariate most highly associated (smallest p-value based on a univariate mixed effects model) to the outcome variable is used in the multiple mixed effects model.

A backward stepwise elimination procedure with $p>0.10$ for exclusion is used in order to reduce the model to the best set of predictors that explain the variability in the outcome endpoint. Once the reduced model is achieved, each of the eliminated covariates is reintroduced back into the model one at a time in order to check for possible residual confounding. If reintroduction changes the coefficient for any of the covariates of the reduced model by more than 10% it is retained in the model. The multiple linear mixed effects model explains the association between actigraphy endpoints and WTS level bins (distance groups as well as other covariates such as responses to the PSQI).

Assumptions of normality and equal variance are tested for in the final multiple mixed effects models using the residuals of the final models. This tests that the residuals are normally distributed (q-q normality plot) with homoscedastic variance (no pattern in the plot of residuals versus predicted variables, as well box-plots for each group within a variable has a similar spread with respect to the outcome variable). Diagnostic tests for detecting influential data are conducted to study potential outliers or influential observations. A series of five diagnostic testse for detecting influential data are conducted to study potential outliers or influential observations. When an observation is considered to be an outlier or influential (failed 3 of the diagnostic tests), sensitivity analysis is conducted. For significant covariates containing more than two levels, pair wise tests are performed by applying Tukey's pair-wise test to compare all levels to one another. This is done in order to control the Type I error rate to less than 0.05.

Finally, in order to test the within-subject variability between WTS level bins (or distance groups) a separate linear mixed effect model is fit to each WTS level bin (or distance group) separately. A likelihood ratio test is performed in order to test the hypothesis of no within-subject variability difference between WTS level bins, or distance groups. Bonferroni adjustment is used to adjust for all the pairwise tests, in order to ensure that the Type I error rate is less than 0.05.

Statistical analysis is performed using software package Statistical Analysis System version 9.2 and R Core Development Team for analysis. Unless otherwise indicated, a 5% statistical significance level (α=0.05) is implemented throughout.

CLOSING REMARKS

Results, anticipated for late 2014, are expected to strengthen the scientific evidence base that supports decisions, advice and policies regarding proposals for wind turbine development, installations and operations in Canada. Taken together with other research, this study will contribute to the global understanding of the relationship between exposure to WTS and community health.

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FOOTNOTES

a. This paper is intended to serve as a more detailed and technical description of the research methodology originally described by the same authors on the Health Canada website http://www.hc-sc.gc.ca/ewh-semt/consult/_2013/wind_turbine-eoliennes/research_recherche-eng.php

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c. Brief biographies for Health Canada's Expert Committee (many of whom are authors of this paper) can be found at http://www.hc-sc.gc.ca/ewh-semt/consult/_2013/wind_turbine-eoliennes/committee_comite-eng.php

d. It is recognised that indoor sound is the sum of ambient sound due to indoor or other external sources, including wind turbines. As a result, depending on the distance from the wind turbines, it may not be possible to say that a person's response at home is due to the WTS. This is particularly the case as distance from wind turbines increase and local ambient sound far exceeds indoor sound due to operational wind turbines.

e. Diagnostic tests for detecting influential or outlier observations include: 1) absolute value of studentized residuals are within 2 units; 2) Cook's D is within 2 units; 3) Mahalanobis distance is less than upper 95% tail of the chi-square distribution with k degrees of freedom (where k is the number of parameters in the model); 4) the restricted likelihood distance is less than upper 95% tail of the chi-square distribution with k degrees of freedom; and 5) absolute value of the covariance ratio statistic less 1 is within 3k/n units (n is the number of observations in the model)

Community Noise Management and Control: Some Successes and Some Challenges

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ABSTRACT

Over recent decades there have been some clear achievements in the acknowledgement of the importance of addressing noise in the community. The focus has been on the major noise sources associated with transportation and industry that globally affect the larger number of people. The publication of guidelines for noise level limits and for establishing noise control policies and approaches to noise management provides a good basis for further applications. This paper discusses some of the successes and also some of the remaining challenges in developing and adopting the most appropriate noise management and control policies.

INTRODUCTION

Noise in human settlement, whether it be called community noise or environmental noise, is acknowledged as being a major problem around the world. It is not unreasonable to say that at some time everyone who lives in or interacts within a community has been exposed to noise generated by others and to some extent has been annoyed or disturbed by that noise. While those who live in cities and towns are exposed more frequently to such noise, even those who seek a quiet rural life will still experience some noise generated by the activities of others. Community noise is not a new problem, as Juvenal the poet and writer in ancient Rome complained about the development of the city and that "*the movement of heavy wagons through narrow streets, the oaths of cattle-drovers would break the sleep of a deaf man....*" The noise from horse drawn vehicles on the cobblestones caused sleep disturbance in Medieval Europe. The control measures implemented then were similar to what we would do today: either the wagons were banned from the city streets at night or straw or dirt was added to the road in an attempt to achieve a quieter road surface.

Since the days of Ancient Rome and Medieval Europe there has been an increase in the types of noise, the levels of noise and the number of people annoyed and disturbed by the noise. This paper will consider some aspects of community noise management and control over recent decades and discuss some of the successes and challenges that still need attention.

ACKNOWLEDGEMENT OF THE PROBLEM

In part because the number of people affected has increased with the increasing population density in towns and cities, community noise can no longer be ignored. International and national organizations have acknowledged the importance of identifying, reducing and managing environmental noise to reduce the negative impacts. One example is that the very first paragraph of DIRECTIVE 2002/49/EC from the European Union[1] which states:

> *It is part of Community policy to achieve a high level of health and environmental protection, and one of the objectives to be pursued is protection against noise. In the Green Paper on Future Noise Policy, the Commission addressed noise in the environment as one of the main environmental problems in Europe.*

And for assessment of the effects, when there is insufficient protection against such noise, the outcomes of the study by the World Health Organization (WHO) on the Burden of Disease from Environmental Noise[2] concluded that the estimate of the disability-adjusted life years (DALYs):

> *.... lost from environmental noise in the western European countries are 61,000 years for ischaemic heart disease, 45,000 years for cognitive impairment of children, 903,000 years for sleep disturbance, 22,000 years for tinnitus and 654,000 years for annoyance. If all of these are considered together, the range of burden would be 1.0–1.6 million DALYs. This means that at least 1 million healthy life years are lost every year from traffic-related noise in the western European countries, including the EU Member States.*

With statistics like that it is not easy for national bodies responsible for the well-being of the community to ignore the extent of the problem. And indeed

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the WHO itself has undertaken work in recent years on setting goals guidelines for noise exposure. The document on Community Noise Guidelines was produced in 1999[3] and in 2009 has been followed up with Night Noise Guidelines For Europe[4], and further reports are being prepared.

Another influential body that has been active in seeking ways to reduce environmental noise is the International Council of Academies of Engineering and Technological Sciences (CAETS). This council considered noise as part of their study on Environment and Sustainable Growth[5] and stated that while much improvement had been achieved globally in relation to other environmental pollution, *environmental noise is a constraining factor for sustainable development.*

As Lang and Khilman summarized in their paper at Internoise 2011[6], there are various ongoing activities within CAETS in order to work towards dealing with this issue. These include a CAETS Noise Control Technology Committee (NCTC) which has been given the mission to provide *an active, science-based support for noise policymakers on technological options for a quieter world*.

The International Institute of Noise Control Engineering (I-INCE) has a memorandum of agreement with CAETS and the Chair and Secretary of the NCTC are Khilman and Lang[7]. This committee arranges for participation in international meetings dealing broadly with environmental issues as well as organizing symposia specifically on noise – for example, the forum on "Lessening the Severe Health Effects of Traffic Noise in Cities by Reducing Emissions" is to be held following the Internoise 2013.

While international bodies can identify the problem and even suggest guidelines to reduce the extent of the effects, it is only when each country or region adopts policies that require compliance with limiting levels of noise that there will be an overall improvement in the environment. In their summary of the findings of the Team 9 of the International Commission on the Biological Effects of Noise (ICBEN), on progress in noise policies Finegold at al[8] reported that *as* *before, much of this progress was made in the European Union, although other areas of the world demonstrated a continuing commitment to improvement on these issues, especially in Asia and North America while in developing countries with their higher noise levels the problem of noise exposure has been hardly recognized.*

In developing countries not only is there very limited attention to environmental noise, there is concern that the noise policies adopted in other countries may not be the most applicable. As discussed by Finegold et al[8], an international consortium has been set up to work in a coordinated international effort to explore this issue and facilitate discussions necessary on noise research and noise policy within developing and emerging countries. This consortium has already organized and sponsored workshops and special technical sessions at relevant conferences – a recent being the special session during Acoustics 2012 in Hong Kong.

So in recent decades there is a clear message from International organizations that environmental noise is a problem, that it affects persons in the community, and that steps should be taken to reduce this impact. While most western countries have clearly defined noise policies which attempt to reduce excessive noise exposure, there is still a great challenge in the developing countries to acknowledge the importance of the problem and to encourage the adoption of appropriate noise control policy for the health and well-being of the community.

SETTING THE NOISE LIMITS

For any noise policy there needs to be goals and a mechanism for ensuring compliance with those goals. The most practical way to achieve this is to define criteria or noise limits — either emission or immission limits. Such limits not only provide a clear statement to those who are responsible for the noise source and the community that may be affected, but also allow for quantitative assessment of the noise. When selecting these limits, the findings from investigations of health effects and dose-response relationships and other studies provide the basis for guidance on limits to noise. Surveys to establish these relationships require large sample sizes and hence most of this work has been directed to the effects of those noises that affect large communities — i.e. primarily transportation noise sources.

Yano et al[9] in their paper on Community Response to Noise summarized the recent activities of the ICBEN noise team 9 in this area. While there have been a number of separate studies since the 1980's aimed to develop and refine dose response relationships there is "*an enormous spread in the data from different surveys*." The establishment by Fields et al[10,11] of some standard questions to be used in surveys has helped to allow for more effective and accurate comparison of data obtained. However Yano et al[9] identified that the "railway bonus" is an example of the diversity of reactions to noise and the challenge this places in attempts to establish international noise dose relationships. This 'bonus' arose from analysis of many surveys that indicated that at equal exposure, railway noise leads to a lower percentage of annoyed people than road traffic noise. In their final report on noise annoyance correction factors, the International Union of Railways[12] questioned this bonus particularly in the light of new and extended railway lines. Yano et al[9] further questioned the applicability of the 'bonus' as studies in Asia have not revealed lesser annoyance to railway noise.

While noise from transportation clearly affects the greatest number of persons across the globe, there are other sources that lead to annoyance reactions in the community. These range from industry and infrastructure such as wind turbine farms or gas fired power stations to more local issues such as outdoor concerts, festivals and sporting activities and, of course, noisy neighbors. In developing noise policy to deal with this range of noise sources, the regulators frequently refer to the precedents of guidelines and limits set in other countries for a similar types of noise. In 2009 I-INCE published the report from the Technical Study group led by Tachibana and Lang on "Survey of Legislation, Regulations, and Guidelines for Control of Community Noise"[13]. This committee sought to document "*legislation, regulations, and guidelines related to the control of community noise*" from around the world and provides a series of tables. These tables are a valuable comparison guide between countries, and while approximately 60% of the policies relate to transportation noise, the remainder provide some indication of the approaches to control all other noise sources. However there is clearly some way to go to provide rigorous evidence for appropriate guidelines for the wide range of noise sources that exist in modern communities.

ASSESSING THE NOISE

Once a policy and the noise limits have been established, it is important to have an assessment process in place to ensure that there is compliance with the limits. The technical aspects of noise measurement have shown great advances in recent decades. Even a basic sound level meter now has the processing and storage capacity to provide the noise level in a range of metrics. With more sophisticated noise logging it is no longer necessary for personnel to be present at the noise — the audio signal can be sent to a remote location or it can be stored for listening to at a later time. It may not be long before the need to have processing and some buffer storage at the monitoring location may be replaced with only the bare essentials of a transducer at a sensor node with the storage and data analysis moved to a centralized computer. Botteldooren et al[14] recently explained their "internet of sound observatories" and the early implementation of such a system.

When the noise source under investigation is clearly the main source of noise in the area, as is the case for those areas near busy roads, airports and industry, the monitoring and assessment of the noise is reasonably straight forward. However when the compliance levels for the new activity are above the background, but still within the ambient noise in the area, the assessment becomes more challenging. Take for example the case of noise from a mine in a rural area. The background noise levels are very low as it is a rural area, however the ambient level with the day to day rural activities can be much higher. The compliance noise limits are typically set in accord with the usual guideline of 5 dB above background over a 10 or 15 min time period. When measuring noise which is so close to a low background noise, any other noise in the area can affect the results so that it is extremely difficult to assess if the mine is actually in compliance. The other consideration is that even when the noise from the mine is well below compliance, due to the nature of the noise being different to the usual 'rural' activity noise, the characteristics of the mine noise can be clearly noted and this leads to the expression of annoyance by the residents.

Another example when the usual method for assessing noise has limitations is for recreation activity noise such as from motor sports venues. When it is a major race through the main streets, or when residential areas are close to a facility, the noise may be dominant and clearly be heard and measured for comparison with the guideline noise limits. However at greater distances the noise from the vehicles on the track may be well within the 'background' but can be clearly identified. In part this may be due to the frequency characteristics of the vehicle noise, in part it may be due to the short term rise and fall time for the sound from each vehicle and in part it may be due to the repetition as the vehicles take generally much the same time to go around the track. The outcome is that there is a genuine concern by the residents to the noise but it is challenging to measure and assess such noise.

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ESTABLISHING THE POLICY

Establishing noise policy essentially requires a decision on the appropriate noise limits and a mechanism to ensure that those noise limits are complied with. From the regulator viewpoint, a successful noise policy is one that after implementation there are a minimal number of complaints from the community. From the proponents' viewpoint, a successful policy is one for which there is a cost effective reasonable and feasible solution to the control of the noise output. From the community's viewpoint, a successful policy is one that provides them satisfaction with their acoustic environment, a mechanism for complaints should they be annoyed and some evidence that there is consideration given to their concerns. I-INCE Technical Study Group 6 under the leadership of Larry Finegold investigated this and the final report[15] provides guidance on guidelines on environmental noise impact assessment and mitigation. This publication provides a flow chart to demonstrate the various elements of the process that work together to establish an appropriate policy.

One of the recommendations from this study was that effective policy needs to allow for a flexible approach as long as it meets with the community expectations. A negotiated agreement could be an outcome when the noise control solutions required to meet the compliance noise levels that would normally apply for other industries or undertakings are not reasonable or feasible for the proponent. If the community is involved with the discussion, then they may be willing to accept a little higher than the usual noise limit as long as there are some benefits, such as limits to hours of work or even a financial contribution to community activities.

As discussed above, much effort has been applied to providing guidelines for those noise sources that affect large numbers of the population. For other noise sources in the community there is less guidance internationally and a flexible approach is particularly important when there are community benefits from the activity. The noise from recreation activities is one example where some of the community benefits from the opportunities provided by the activity yet other parts of the community could be adversely affected. Live music from venues, particularly amplified music, is one recreation activity which has become an increasing problem for the regulators seeking to establish a suitable policy. In some situations it may be appropriate to apply noise limits that require the venue to install extensive noise control measures to keep the noise within the venue. In other situations it may be more appropriate to consider the culture of the area, the fact that the area has a tradition of being an area or a street where the community goes to enjoy to music. Internationally recognized for Jazz music is Bourbon Street in New Orleans, Louisiana. Woolworth[16] has discussed the complexity of establishing a policy to deal with the music/noise that is part of the culture and tradition of the area. However many cities have such areas and less well known may be Fortitude Valley in Brisbane, Australia[17]. A pragmatic approach for these situations is to clearly identify the area as a special area and not subject to the usual regional noise policy. Having provided the message that this area is different to the rest of the city, the next step is to negotiate and reach a compromise on reasonable limits applicable within that area. The policy may involve a number of elements that include a limit to the noise at the source, a limit to the hours of operation and perhaps more stringent limits for new facilities.

A subject that is particularly controversial in many countries relates to policies that deal with noise from wind turbines. One example is the Australian Government Senate Select Committee investigating the community concerns after they received over 1,000 submissions. Their report[18] identified that there was a "*lack of adequately resourced epidemiological and laboratory studies of the possible effects of wind farms on human health*" and while the Government response did not specifically allocate funding to such investigations, there is encouragement for support for such studies via existing funding agencies. In contrast, Health Canada in July 2012 has specifically supported a "Wind Turbine Noise and Health Study"[19] with the results expected in 2014. Until the outcome of such studies really provide reliable guidelines for limiting noise from wind farms, the approaches will be similar to those for other types of general noises, namely comparison with the background noise level; for example, the guidelines[20] and the accompanying best practice guide recently released in the UK[21].

CONCLUSION

Over recent decades there have been some clear achievements in the acknowledgement of the importance of addressing noise in the community. The focus has been on the major noise sources associated with transportation and industry that globally affect a large number of people. The publication of guidelines for noise level limits and for establishing noise control policies and approaches to noise management provides a good basis for further improvements. However, there are still some challenges to increase the awareness of such guidance and encourage appropriate policies in developing countries. There are also still a number of noise sources for which there are challenges in developing and adopting the most appropriate noise management policies.

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