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Wind Turbine Noise and Health Study: Summary of Results

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Summary

A cross-sectional epidemiological study was initiated by Health Canada to investigate the prevalence of health effects or health indicators among a sample of Canadians exposed to wind turbine noise (WTN) using both self-reported and objectively measured health outcomes. The sample was drawn from communities in Ontario (ON) and Prince Edward Island (PEI) where there were a sufficient number of dwellings within the vicinity of wind turbine installations. One participant between the ages of 18-79 years was randomly selected from each household. The final sample included 1238 participates (606 males, 632 females) living between 0.250 and 11.22 km from operational wind turbines. The response rate was 78.9% and did not significantly vary across sampling strata or between provinces. Modelled A- and C-weighted WTN levels reached 46 dBA and 63 dBC, respectively, however, dBC analysis yielded limited additional value as results were highly correlated with dBA (r=0.94). Sample characteristics were relatively homogenous, with some minor differences found in age, employment, type and ownership of dwelling. WTN exposure was not found to be related to hair cortisol concentrations, blood pressure, resting heart rate or any of the measured sleep parameters (i.e., sleep latency, sleep time, rate of awakenings, sleep efficiency). Self-reported results obtained through an in-person questionnaire do not provide support for an association between increasing WTN levels and self-reported sleep disturbance, use of sleep medication, or diagnosed sleep disorders. Similarly, no significant association was found between WTN levels and self-reported migraines, tinnitus, dizziness, diabetes, hypertension, perceived stress or any measure of quality of life. Statistically significant exposure-response relationships were observed between increasing WTN levels and an increase in the prevalence of long term high annoyance towards several wind turbine features, including: noise, shadow-flicker, visual impacts, blinking lights and vibrations. The influence of background noise on annoyance and the association between WTN annoyance and other reported and measured outcomes is presented.

1. INTRODUCTION

In Canada, jurisdiction for the regulation of noise is shared across many levels of government. Health Canada's mandate with respect to wind power includes providing science-based advice, upon request, to federal departments, provinces, territories and other stakeholders on the potential impacts of WTN on community health and well-being. Provinces and territories, through the legislation they have enacted, make decisions in relation to areas including installation, placement, sound levels and mitigation measures for wind turbines.

Globally, wind energy is relied upon as an alternative source of renewable energy. In Canada wind energy capacity has grown from approximately 137 Megawatts (MW) in 2000 to 9,698 megawatts (MW) in 2015 (CANWEA, 2015). At the same time, there has been concern from some Canadians living within the vicinity of wind turbine installations that their health and well-being are negatively affected from exposure to WTN.

The scientific evidence base in relation to WTN exposure and health is limited, which includes uncertainty as to whether or not low frequency noise (LFN) and infrasound from wind turbines contributes to the observed community response and potential health impacts. Studies that are available differ in many important areas including methodological design, the evaluated health effects, and strength of the conclusions offered (Krogh et al. 2011; Mroczek et al. 2012; Nissenbaum et al. 2012; Pawlaczyk-Luszczyriska et al. 2014; Pedersen and Persson Waye 2004, 2007; Pedersen et al. 2009; Shepherd et al. 2011; Tachibana et al. 2012).

In July 2012, Health Canada announced its intention to undertake a large scale epidemiology study in collaboration with Statistics Canada. The study, entitled the: *Community Noise and Health Study* was launched to support a broader evidence base on which to provide federal advice and in acknowledgement of the community health concerns expressed in relation to wind turbines.

2. EXPERIMENTAL DESIGN

The study was undertaken in two Canadian provinces, Ontario (ON) and Prince Edward Island (PEI), where there were a sufficient number of dwellings within the vicinity of wind turbine installations. The study consisted of three primary components: an in-person questionnaire, administered by Statistics Canada to randomly selected participants living at varying distances from wind turbine installations; collection of objectively measured outcomes that assess hair cortisol, blood pressure and sleep quality; and, more than 4000 hours of WTN measurements conducted by Health Canada to support the calculation of WTN levels at residences captured in the study scope.

2.1 Calculation of outdoor WTN levels at dwellings

Sound pressure levels were estimated at each receptor using both ISO 9613-1 (ISO, 1993) and 9613-2 (ISO, 1996) as incorporated in the commercial software CadnaA version 4.4 (Datakustik® 2014). The calculations included all wind turbines within a radius of 10 km, and were based on manufacturers' octave band sound power spectra at 10 metre height, 8 metres

per second wind speed for favourable propagation conditions. The few dwellings beyond this distance were assigned the same calculated WTN value as dwellings at 10 km. The manufacturers' data was verified for consistency using on-site measurements of wind turbine sound power. To support the assessment and reporting of data, and permit comparisons to other studies, residences were grouped into different categories of calculated outdoor A-weighted WTN levels as follows: <25; 25−<30; 30−<35; 35−<40; and 40−46.

2.2 Calculation of outdoor nighttime background sound levels at dwellings

As a result of certain meteorological phenomena (atmospheric stability and wind gradient) coupled with a tendency for background sound levels to drop throughout the day in rural/semi-rural environments, WTN can be more perceptible at the receptor during nighttime (Pedersen et al. 2010 a, b; van den Berg 2011, 2013). It is possible to estimate nighttime sound pressure levels in Canada using the provincial noise regulations for Alberta, Canada (AUC 2013), which estimates ambient noise levels in rural and suburban environments. When modelled in accordance with these regulations, estimated levels can range from 35 dB to 51 dB, based on dwelling density per quarter section, which represents an area with a 451 m radius, and distance to heavily travelled roads or rail lines. In ON, road noise for the six lane concrete #401 Highway was calculated using the US Traffic Noise Model (Federal Highway Administration (FHWA) TNM® 1998) module in the CadnaA software. This value was used when it exceeded the Alberta noise estimate (AUC 2013).

2.3 Questionnaire development

During early stages of development, a draft questionnaire in both English and French underwent pilot testing by Statistics Canada in the form of in-home interviews on a sample of 24 adults living near wind turbine installations in ON and Quebec. The location and participants involved in the pilot testing were not part of the final study sample. The final questionnaire reflected feedback following pilot testing and the collective input from subject matter experts and professionals with expertise in the field of community noise, social surveys, and direct physical health measures. The questionnaire underwent additional modifications subsequent to a 60 day public consultation period on the study design. To support the integrity of the study, the consultation did not include the questionnaire itself, but rather identified the themes addressed within the study.

The final questionnaire consisted of modules on demographics, noise annoyance, health effects, medication use, specific illnesses, sleep disturbance, and prevalent chronic disease. In addition to these modules, validated psychometric scales were incorporated, without modification, into the questionnaire. Self-reported stress was assessed using the Perceived Stress Scale (PSS) (Cohen et al. 1983), Quality of Life was assessed with the World Health Organization's (WHO) Quality of Life- BREF (WHOQOL-BREF) (WHOQOL Group 1998; Skevington et al. 2004) and the Pittsburgh Sleep Quality Index (PSQI) (Buysse et al. 1989) was used to measure self-reported sleep quality.

A computer-assisted personal interviewing (CAPI) technique was applied to capture questionnaire responses from participants. CAPI allows for custom interviews for every

respondent based upon their individual characteristics and survey responses. Its functionality includes the ability to automatically skip questions not applicable to a respondent, in addition to embedded checks for the identification of inconsistent or out-of-range responses. For the latter, on-screen prompts automatically identified invalid entries allowing for immediate feedback to the participant and correction of inconsistencies. Encryption software was applied to ensure the confidentiality of the data. The final questionnaire is publicly accessible in Canada's two official languages, French and English, through the Statistics Canada website (Statistics Canada 2014).

2.4 Data collection

The survey data was collected by 16 Statistics Canada trained interviewers between May and September, 2013. Interviewers introduced the study as the *Community Noise and Health Study*. The purpose of the study, the general content and the time commitment were communicated to potential participants at which time it was also noted that participation was voluntary and that any information provided would be kept confidential under the authority of the Statistics Act (Statistics Act, R.S.C. 1985, c. S-19). Once a roster of all adults (between the ages of 18 and 79 years) living in the dwelling was compiled, one individual from each household was randomly invited to participate in the study. No substitutions were permitted under any circumstances.

Detailed information on the study methodology, including the 60-day public consultation and peer review process is available on the Health Canada website. The detailed methodology for the study was also published by Michaud et al. (2013).

2.5 Statistical analysis

The analysis for dichotomous (categorical) endpoints (e.g., proportion of respondents who were highly annoyed to WTN, highly sleep disturbed, etc..), continuous endpoints (e.g., WHOQOL-BREF domains, hair cortisol, PSS, blood pressure and heart rate), and repeated measures endpoints (e.g., sleep actigraphy) all follow very closely to the description as outlined in Michaud et al. (2013), which gives a summary of the pre-data collection study design and objectives, as well as proposed data analysis. All models (for categorical, continuous and repeated measures endpoints) were adjusted for provincial differences. Province was initially assessed as an effect modifier. When the interaction between WTN and province was significant, separate models were reported for each province. When the interaction was not statistically significant, province was treated as a confounder in the model.

For the analysis of dichotomous endpoints, 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). When the logistic regression model was fit, the Nagelkerke pseudo R^2 and Hosmer-Lemeshow (H-L) p-value are reported for all models. The Nagelkerke pseudo R^2 is a measure of the explained variance in the model and is referred to as a generalization of the coefficient of determination. When the p-value from the H-L goodness of fit test is >0.05 this indicates there is no statistically significant difference between the modelled and observed data.

In the analysis of repeated measures (longitudinal data) endpoints, data were modelled using linear mixed effects models (LMM), or generalized linear mixed models (GLMM) for counts. The generalized estimating equations (GEE) method, as available in Statistical Analysis System (SAS) procedure PROC GENMOD, was applied to the repeated measures data (Liang and Zeger, 1986; Stokes et al. 2000). PROC GENMOD addresses continuous or discrete responses based on a quasi-likelihood approach when modelling correlated responses. The within-subjects correlations were examined by comparing the quasi-likelihood information criterion (QIC) based on GEE with different working correlation matrix structures (unstructured, compound symmetry and autoregressive of first order), where smaller QIC values are considered to be a better fit of the model. As well, the within-subject correlations were examined graphically for the identification of obvious patterns. The simplest model with the best fit which follows the pattern as observed in the graphs is chosen to model the within-subject variability. The advantage of the GEE method is that they use all available data to estimate individual subject variability, but are not sensitive to the number of missing values.

For all types of endpoints when building the multiple regression models, all potential variables that were significant in the univariate analysis at the 20% level were considered for entry into the models. Variables remained in the final model if they were significant at a 10% level.

Statistical analysis was performed using SAS version 9.2. A 5% statistical significance level is implemented throughout unless otherwise stated. In addition, Bonferroni corrections (for categorical endpoints) and Tukey corrections (for continuous and repeated measures endpoints) are made to account for all pairwise comparisons to ensure that the overall Type I (false positive) error rate is less than 0.05.

The study was approved by the Health Canada and Public Health Agency of Canada Review Ethics Board (Protocol # 2012-0065 and #2012-0072).

3. RESULTS

Health Canada has completed its preliminary analysis of the data obtained. Research findings are presented below in accordance with the study component in which they were obtained i.e. in-person, self-report questionnaire findings, objectively measured responses, and noise measurements and calculations. As with other studies of this nature, a number of limitations and considerations apply to the study findings including:

- results may not be generalized to areas beyond the sample as the wind turbine locations in this study were not randomly selected from all possible sites operating in Canada;
- results do not permit any conclusions about causality; and,
- results should be considered in the context of all published peer-reviewed literature on the subject.

3.1 Outdoor WTN levels at dwellings

3.1.1 A-Weighted

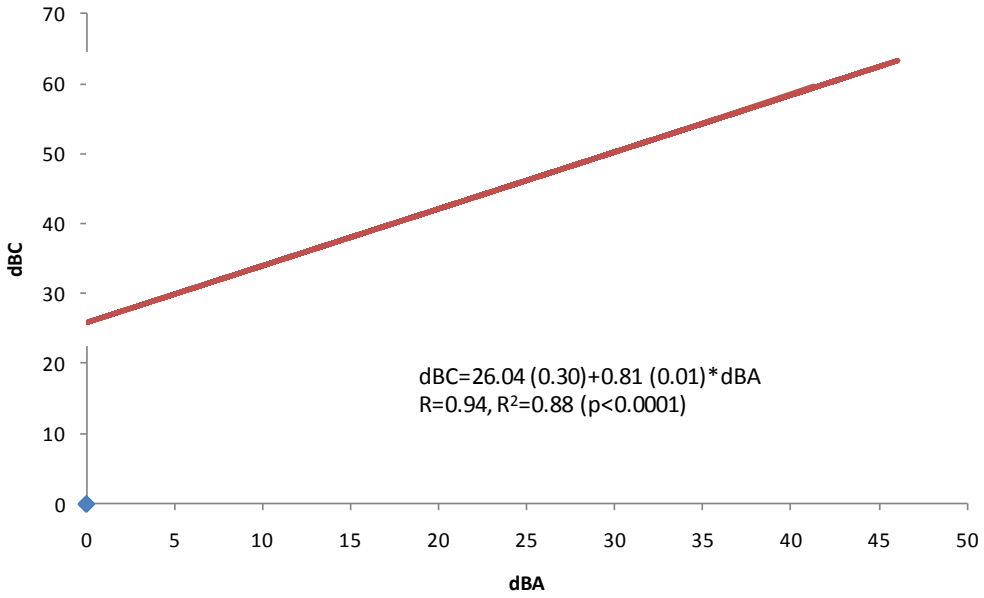
More than 4000 hours of WTN measurements conducted by Health Canada supported the calculations of A-weighted WTN levels at all 1238 dwellings captured in the study sample. Calculated outdoor A-weighted WTN levels for the dwellings in the study reached 46 dBA for wind speeds of 8m/s for favourable propagation conditions. This approach is the most appropriate to quantify the potential adverse effects of WTN. The calculated WTN levels are likely to be representative of yearly averages with an uncertainty of about +/- 5dB.

3.1.2 Low frequency noise

Wind turbines emit LFN, which can enter the dwelling with little or no reduction in energy potentially resulting in rattles in light weight structures and annoyance (ANSI, 1995). Although the boundaries of LFN are not fixed, it generally includes frequencies between 20Hz and 200Hz. C-weighted sound levels can be a better indicator of LFN in comparison to A-weighted levels, and were calculated in order to assess the potential LFN impacts.

Calculated outdoor dBC levels for dwellings ranged from 24 dBC and reached 63 dBC. Three (3)% of the dwellings were found to exceed 60 dBC. No additional benefit was observed in assessing LFN because C- and A-weighted levels were so highly correlated. Depending on how dBC was calculated and what range of data was assessed, the correlation between dBC and dBA ranged from R=0.84 to R=0.97. Figure I illustrates the correlation when the entire dataset is used (R=0.94). It was therefore not surprising that the relationship between annoyance and WTN levels was predicted with equal strength using dBC or dBA and that there was no association found between dBC levels and any of the self-reported illnesses or chronic health conditions assessed (e.g., migraines, tinnitus, high blood pressure, etc.).

Figure I. Correlation between calculated outdoor A- and C-weighted WTN levels



Sound pressure levels were found to be below the recommended thresholds for reducing perceptible rattle and the annoyance that rattle may cause (ANSI, 1995). As LFN is generally considered to be an indoor noise problem, it was of interest to better understand how much outdoor LFN makes its way into the dwelling. At a selection of representative dwellings, Health Canada measurements showed an average of 14dB of outdoor WTN was blocked from entering a dwelling at low frequencies (16 Hz - 100 Hz) with closed windows compared to an average reduction of 10dB with windows partially open (data not shown).

3.2 Study population and participation

The study locations were drawn from areas in southwestern ON and PEI where there were a sufficient number of dwellings within the vicinity of wind turbine installations. Twelve (12) and 6 wind turbine developments were sampled in ON and PEI, representing 315 and 84 wind turbines respectively. All potential dwellings within approximately 600 m of a wind turbine were selected, as well as a random selection of dwellings between 600 m and 10 km. From these, one person between the ages of 18 and 79 years from each dwelling was randomly selected to participate.

Table I shows the final sample size distributed as a function of distance to the nearest wind turbine. Of the 2004 potential locations identified *a priori* from the address registry, 1570 were found to be valid dwellings during data collection. Of these, a total of 1238 households participated, resulting in an overall participation rate of 78.9%. Participation rate was similar regardless of proximity to wind turbines and equally high in both provinces.

	Distance to nearest wind turbine (km)						
	≤0.55	0.55−<1	1−<2	2−<5	>5	overall	CMH p-value[a]
Range of WTN (dB)	37.4-46.1	31.8-43.6	26.3-40.4	14.6-30.9	0-18.2		
Total potential dwellings[e]	143	887	781	95	98	2004	
ON	76	718	669	60	80	1603	
PEI	67	169	112	35	18	401	
Total number of potential dwellings out-of-scope n(%)[f]	48 (33.6)	158 (17.8)	189 (24.2)	19 (20.0)	20 (20.4)	434 (21.7)	
ON	29 (38.2)	109 (15.2)	166 (24.8)	9 (15.0)	14 (17.5)	327 (20.4)	<0.0001[b]
PEI	19 (28.4)	49 (29.0)	23 (20.5)	10 (28.6)	6 (33.3)	107 (26.7)	0.5263[b]
Demolished	26 (18.2)	25 (2.8)	18 (2.3)	5 (5.3)	8 (8.2)	82 (4.1)	0.0142
Vacant	16 (11.2)	55 (6.2)	56 (7.2)	5 (5.3)	6 (6.1)	138 (6.9)	0.3812
Unoccupied seasonal	2 (1.4)	36 (4.1)	61 (7.8)	7 (7.4)	1 (1.0)	107 (5.3)	
>79 years of age	4 (2.8)	35 (3.9)	50 (6.4)	2 (2.1)	5 (5.1)	96 (4.8)	
Other[c]	0 (0.0)	7 (0.8)	4 (0.5)	0 (0.0)	0 (0.0)	11 (0.6)	
Final number of potential participants[d]	95	729	592	76	78	1570	
Participants n (%)	71 (74.7)	583 (80.0)	463 (78.2)	58 (76.3)	63 (80.8)	1238 (78.9)	0.9971
ON	34 (72.3)	488 (80.1)	396 (78.7)	42 (82.4)	51 (77.3)	1011 (79.2)	
PEI	37 (77.1)	95 (79.2)	67 (75.3)	16 (64.0)	12 (100.0)	227 (77.2)	

[a] The Cochran Mantel-Haenszel chi-square test is used to adjust for province unless otherwise indicated, p-values <0.05 are considered to be statistically significant; [b] Chi-square test of independence; [c] Other out-of-scope locations included dwellings under construction, institution, unavailable to participate and were suppressed here to protect the identify of individual participants; [d] Potential participants from locations established to be valid dwellings (equal to the difference between "Total potential dwellings" and "total number of potential dwellings out of scope") used in the derivation of participation rates.[e] Total potential dwellings is further broken down by total potential dwellings in each province.[f] Total number of potential dwellings out of scope (given as a percentage of total potential dwellings) is broken down by province, as well it is equal to the sum of Demolished, Vacant, Unoccupied, Seasonal, >79 years of age, and Other. The percentage of dwellings that are Demolished, Vacant, Unoccupied, Seasonal, >79 years of age, and Other are based on the total number of potential dwellings in the area. CMH, Cochran Mantel-Haenszel; dB, decibel; km, kilometer; ON, Ontario, PEI, Prince Edward Island.

3.3 Questionnaire results

Results are presented in relation to WTN levels. For findings related to WTN annoyance, results are also provided by proximity to allow for comparisons with other studies. WTN is a more sensitive measure of exposure level and allows for consideration of topography, wind turbine characteristics and the number of wind turbines at any given distance. To illustrate, two similar dwellings may exist in similar environments located at the same distance from the nearest turbine operating in areas with 1 small and 75 large wind turbines respectively. These dwellings would be treated the same if the analysis was conducted using only distance to the nearest wind turbine, however, they would be completely different in terms of their WTN exposure levels.

The following were not found to be associated with WTN exposure:

- self-reported sleep (e.g., general disturbance, use of sleep medication, diagnosed sleep disorders);
- self-reported illnesses (e.g., dizziness, tinnitus, prevalence of frequent migraines and headaches) and chronic health conditions (e.g., heart disease, high blood pressure and diabetes); and
- self-reported perceived stress and quality of life.

While some individuals reported some of the health conditions above, the prevalence was not found to change in relation to WTN levels.

3.3.1 Self-reported sleep

Long-term sleep disturbance can have adverse impacts on health (Knutson et al. 2009; McEwen, 2006; Zaharna and Gulleminault, 2010) and the WHO has proposed limits for protecting against noise-induced sleep disturbance (WHO, 1999, 2009). Self-reported sleep disturbance has been shown in some, but not all, studies to be related to exposure to wind turbines (Knopper and Ollson, 2011; McCunney et al., 2014; Pedersen, 2011).

The Pittsburgh Sleep Quality Index (PSQI) is a frequently used questionnaire for providing a validated measure of reported sleep pathology where scores can range from 0-21 and a global score of greater than 5 is considered to reflect subjective sleep pathology (Buysse et al. 1989). The PSQI was administered as part of the overall questionnaire, which also included questions about the use of sleep medication, prevalence of sleep disorders diagnosed by a healthcare professional and how sleep disturbed people were in general over the last year (i.e. percentage highly sleep disturbed). None of these measures were found to be related to WTN levels (see Table II).

3.3.2 Self-reported health effects

As presented in Table II, results related to the reported diagnosis with a number of health conditions. None of these conditions were found to be associated with WTN levels. These conditions included, but were not limited to chronic pain, high blood pressure, diabetes, heart disease, dizziness, migraines and tinnitus.

3.3.3 Self-reported stress

Exposure to stressors and how people cope with these stressors has long been considered by health professionals to represent a potential risk factor to health, particularly to cardiovascular health and mental well-being (Sapolsky et al. 2000; Stansfeld and Marmot, 2002). The PSS is a validated questionnaire that provides an assessment of the degree to which situations in one's life are appraised as stressful (Cohen et al. 1983). Average PSS scores were not found to be related to WTN levels.

Table II. Self-reported measures related to sleep and illness as a function of WTN levels

	WTN (dBA)						
Variable	<25	25−<30	30−<35	35−<40	40-46	overall	CMH[b] *p*-value
N	84[a]	95[a]	304[a]	521[a]	234[a]	1238[a]	
Health compared to one year ago (n, %Worse) [d]	17 (20.2)	12 (12.6)	46 (15.1)	90 (17.3)	51 (21.8)	216 (17.5)	0.1724
Migraines (n, %)	18 (21.4)	24 (25.3)	56 (18.4)	134 (25.8)	57 (24.4)	289 (23.4)	0.2308
Dizziness (n, %)	19 (22.6)	16 (16.8)	65 (21.4)	114 (21.9)	59 (25.2)	273 (22.1)	0.2575
Tinnitus (n, %)	21 (25.0)	18 (18.9)	71 (23.4)	129 (24.8)	54 (23.2)	293 (23.7)	0.7352
Chronic Pain (n, %)	20 (23.8)	23 (24.2)	75 (24.8)	118 (22.6)	57 (24.5)	293 (23.7)	0.8999
Asthma (n, %)	8 (9.5)	12 (12.6)	22 (7.2)	43 (8.3)	16 (6.8)	101 (8.2)	0.2436
Arthritis (n, %)	23 (27.4)	38 (40.0)	98 (32.2)	175 (33.7)	68 (29.1)	402 (32.5)	0.6397
High Blood Pressure (n, %)	24 (28.6)	36 (37.9)	81 (26.8)	166 (32.0)	65 (27.8)	372 (30.2)	0.7385
Use of high blood pressure in previous month (n, %)	26 (31.3)	34 (35.8)	84 (27.6)	163 (31.3)	63 (27.0)	370 (29.9)	0.4250
History of high blood pressure in family (n, %)	44 (52.4)	49 (53.8)	132 (45.5)	254 (50.6)	121 (53.8)	600 (50.3)	0.6015
Chronic bronchitis, emphysema, COPD (n, %)	3 (3.6)	10 (10.8)	17 (5.6)	27 (5.2)	14 (6.0)	71 (5.7)	0.7676
Diabetes (n, %)	7 (8.3)	8 (8.4)	33 (10.9)	46 (8.8)	19 (8.2)	113 (9.1)	0.6890
Heart disease (n, %)	8 (9.5)	7 (7.4)	31 (10.2)	32 (6.1)	17 (7.3)	95 (7.7)	0.2110
%Reporting high sleep disturbance[e] (n, %)	13 (15.7)	11 (11.6)	41 (13.5)	75 (14.5)	24 (10.3)	164 (13.3)	0.4300
Diagnosed sleep disorder e.g., sleep apnea or insomnia (n, %)	13 (15.5)	10 (10.5)	27 (8.9)	44 (8.4)	25 (10.7)	119 (9.6)	0.3102
Weekly use of sleep medication (n, %)	16 (19.0)	18 (18.9)	39 (12.8)	46 (8.8)	29 (12.4)	148 (12.0)	0.0083
Restless leg syndrome (n, %)	7 (8.3)	16 (16.8)	37 (12.2)	81 (15.5)	33 (14.1)	174 (14.1)	
Restless leg syndrome (ON)	4 (6.7)	15 (17.4)	27 (11.0)	78 (17.3)	28 (16.5)	152 (15.0)	0.0629 [f]
Restless leg syndrome (PEI)	3 (12.5)	1 (11.1)	10 (16.9)	3 (4.2)	5 (7.8)	22 (9.7)	0.1628 [f]
Use of medication for anxiety or depression (n, %)	11 (13.1)	14 (14.7)	35 (11.5)	59 (11.3)	23 (9.8)	142 (11.5)	0.2470
QoL past month[g]							
Poor (n, %)	9 (10.8)	3 (3.2)	21 (6.9)	29 (5.6)	20 (8.6)	82 (6.6)	0.9814
Good (n, %)	74 (89.2)	92 (96.8)	283 (93.1)	492 (94.4)	213 (91.4)	1154 (93.4)	
Health past month [g]							

Dissatisfied (n, %)	13 (15.5)	13 (13.7)	49 (16.1)	66 (12.7)	36 (15.4)	177 (14.3)	0.7262
Satisfied (n, %)	71 (84.5)	82 (86.3)	255 (83.9)	455 (87.3)	198 (84.6)	1061 (85.7)	
PSQI mean	6.22 (5.32, 7.11)	5.91 (5.05, 6.77)	6.00 (5.51, 6.50)	5.74 (5.33, 6.16)	6.09 (5.55, 6.64)	5.94 (5.72, 6.17)	0.7497 (ANOVA)
PSQI >5[h] (n, %)	40 (49.4)	45 (48.9)	138 (46.5)	227 (44.4)	106 (46.7)	556 (46.0)	0.4740[i]
PSS mean(95%CI)	11.68 (10.23, 13.13)	11.17 (9.77, 12.57)	11.30 (10.49, 12.11)	11.40 (10.73, 12.08)	12.27 (11.39, 13.15)		0.6606[i]

[a]Columns may not add to total due to missing data; [b]The Cochran Mantel-Haenszel chi-square test is used to adjust for provinces unless otherwise indicated, p-values <0.05 are considered to be statistically significant; [c]Highly sensitive includes the two ratings: “very” and “extremely” sensitive; [d]Worse consists of the two ratings: "Somewhat worse now" and "Much worse now"; [e]High sleep disturbance consists of the two ratings: “very” and “extremely” sleep disturbed; [f]Chi-square test of independence; [g]Quality of Life and Satisfaction with Health were assessed with the two stand alone questions on the WHOQOL-BREF. Reporting “poor” overall Quality of Life reflects a response of “poor” or “very poor”, and “good” reflects a response of “neither poor nor good”, “good” or “very good”. Reporting “dissatisfied” overall Satisfaction with Health reflects a response of “very dissatisfied” or “dissatisfied”, and “satisfied” reflects a response of “neither satisfied nor dissatisfied”, “satisfied” or “very satisfied”; [h]an overall score above 5 on the PSQI is considered to represent subjective sleep pathology; [i]analysis performed using logistic regression. CMH, Cochran Mantel-Haenszel; dB, decibel; km, kilometer; ON, Ontario, PEI, Prince Edward Island.

3.3.4 Self-reported annoyance

Annoyance is defined as a long-term response (approximately 12 months) of being "very or extremely annoyed" as determined by means of surveys. Reference to the last year or so is intended to distinguish a long term response from one's annoyance on any given day (ISO, 2003).

Statistically significant exposure-response relationships were found between increasing WTN levels and the prevalence of reporting high annoyance. Figure II illustrates that these associations were found with annoyance due to noise, vibrations, blinking lights, shadow and visual impacts from wind turbines. In general, annoyance (of any type) increased with increasing exposure to WTN levels. A statistically significant increase in annoyance was found when WTN levels exceeded 35 dBA.

Figure II. Percentage highly annoyed by features associated with wind turbines

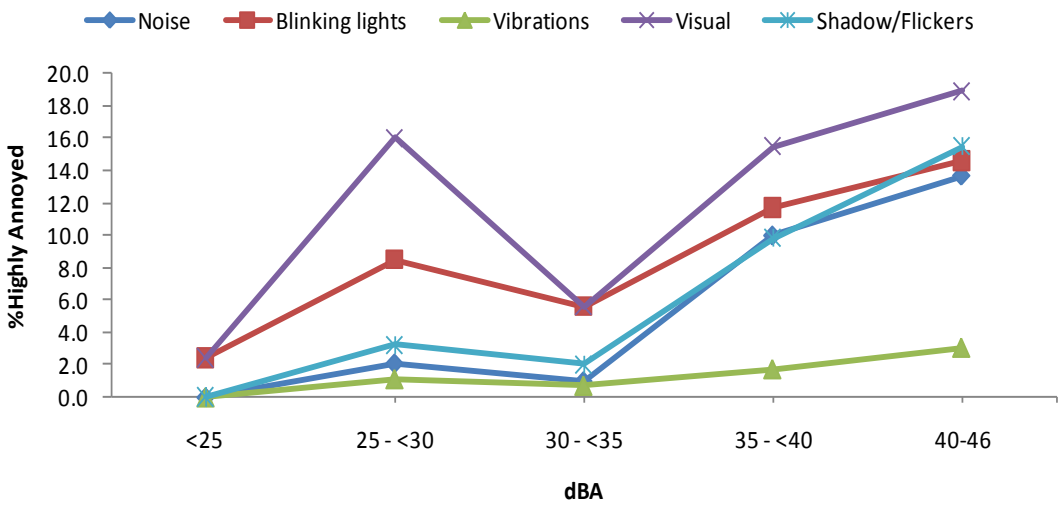


Figure II illustrates the observed prevalence in reported high annoyance to several features associated with wind turbines. There was a tendency for annoyance to increase significantly when WTN levels exceeded 35dBA.

Figure III illustrates the prevalence in high annoyance with WTN in ON and PEI as a function of WTN levels and distance to the nearest wind turbine. At the highest WTN levels (40-46 dBA in both provinces), the following percentages of respondents were highly annoyed by WTN: ON-16.5%; PEI-6.3%. Overall, the pattern of response was similar; however the prevalence of WTN annoyance was 3.29 times higher in ON versus PEI (95% confidence interval, 1.47 - 8.68). Assessed as a function of distance, annoyance was observed to drop at distances between 1-2km in ON, compared to PEI where almost all of the participants who were highly annoyed by WTN lived within 550m of a wind turbine. Investigating the reasons for provincial differences is outside the scope of the current study.

Figure III. Percentage highly annoyed by WTN in ON and PEI

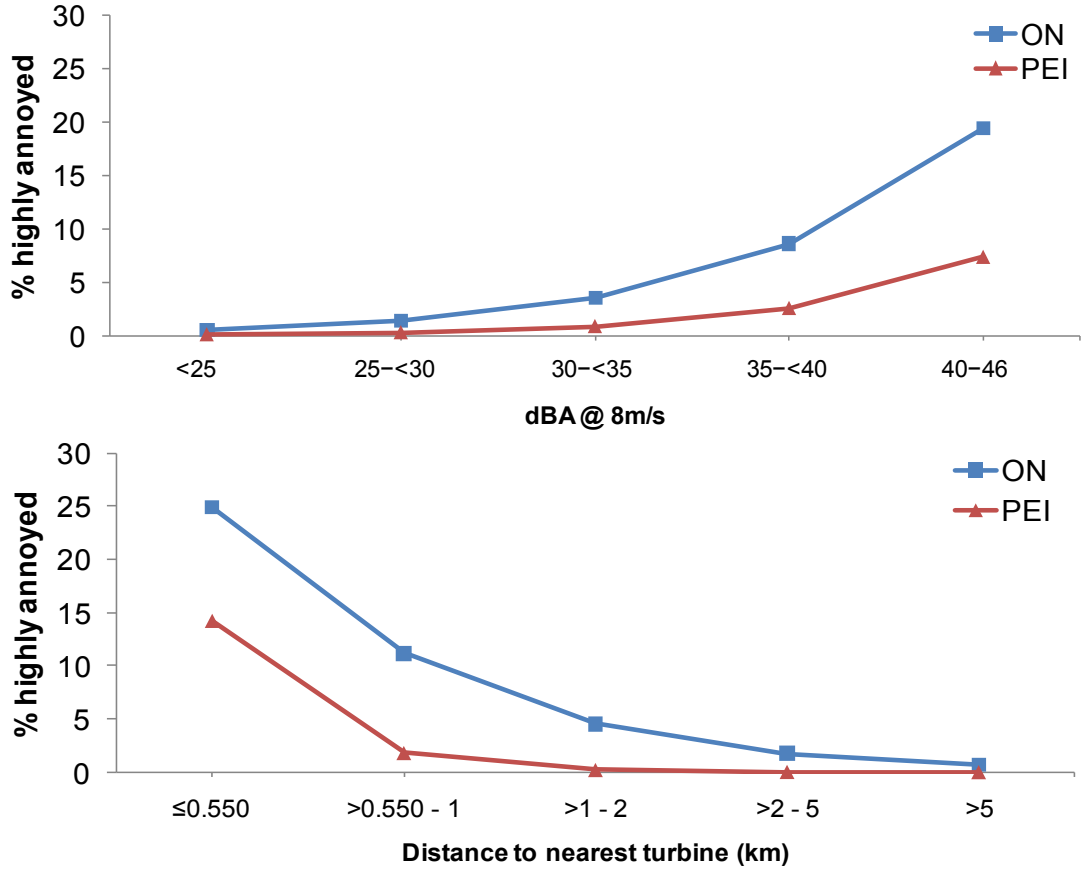


Figure III illustrates the prevalence of high annoyance with WTN in southwestern ON and PEI expressed as a function of WTN levels (top panel) and distance to the nearest wind turbine (lower panel). While the pattern of response was similar in both provinces, the prevalence of WTN annoyance was statistically higher in ON. Fitted results shown.

Additional findings related to reported WTN annoyance included the observation that it was statistically higher in the summer, outdoors and during evening and night time (data not shown).

Considering the difference between background nighttime sound levels and WTN levels, WTN annoyance significantly dropped in areas where calculated nighttime background noise exceeded WTN by 10dB or more (figure IV).

Figure IV. The influence of background nighttime sound levels on the percentage highly annoyed by WTN

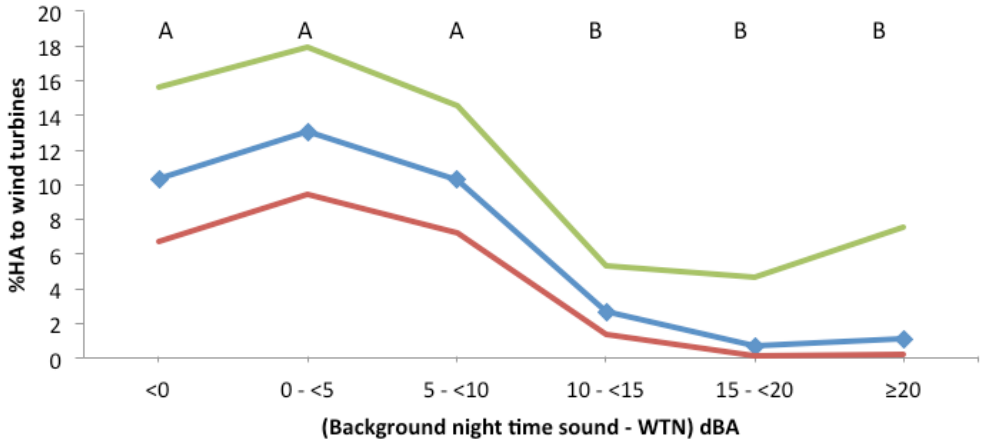


Figure IV illustrates the influence that modelled outdoor background nighttime sound pressure levels was found to have on the WTN annoyance. Background sound levels were calculated following the Alberta noise regulation (AUC, 2013). Results are shown as a function of degree to which background sound levels exceeded WTN levels modelled for wind speeds of 8 meters/second at 10 metre heights, for favourable propagation conditions. There was a significant decrease in the audibility of wind turbines when background levels exceeded WTN levels by at least 5 dB (data not shown), and a decrease in annoyance when the difference exceeded 10 dB. The prevalence of high annoyance between groups with the same letter in the figure are statistically similar (P>0.05), whereas groups with different letters are statistically different (P<0.05). All p-values are Bonferroni adjusted for pairwise comparisons. Green and red lines represent the upper and lower 95% confidence intervals, respectively.

3.3.4.1 Annoyance and health

Irrespective of WTN levels (or the proximity between the dwelling and the wind turbines) WTN annoyance was found to be statistically related to several self-reported health effects including, but not limited to, blood pressure, migraines, tinnitus, dizziness, scores on the PSQI, and perceived stress. WTN annoyance was also found to be statistically related to measured hair cortisol, systolic and diastolic blood pressure. In many cases, these associations were also observed with road traffic noise annoyance. The associations found between WTN annoyance and other health endpoints were no longer significant in any of the final multiple regression models, which adjust for all variables known to have an effect on the factors being assessed (e.g. BMI, smoking status, age, income, other annoyances, etc…).

3.4 Personal benefit and WTN annoyance

Figure V illustrates the audibility of WTN and observed prevalence of WTN annoyance among participants that reported to benefit from having wind turbines in the area. Personal benefit could include rent, payments or other indirect benefits through community improvements. WTN annoyance was significantly lower among the 110 participants who received personal benefit.

Figure V. Response to WTN among participants that personally benefit from having wind turbines in the area

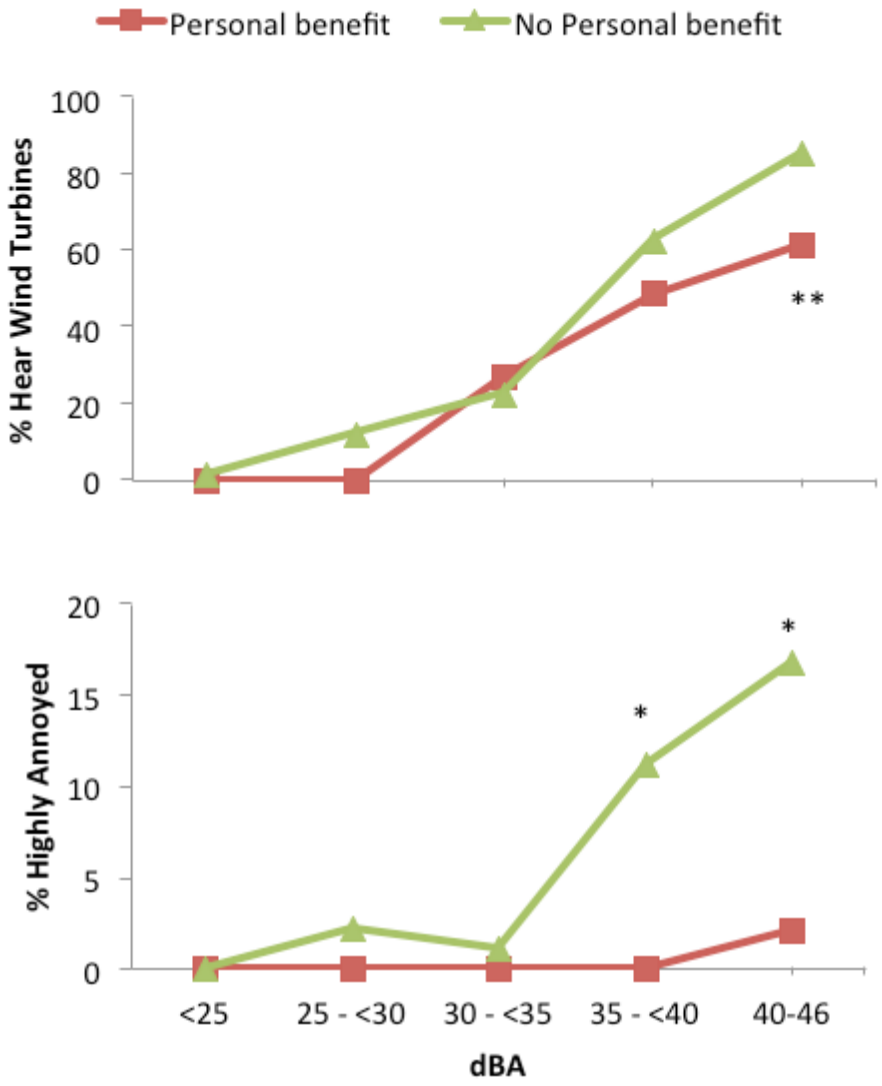


Figure V illustrates the influence that personal benefit was found to have on the reported audibility of wind turbines from inside or outside the dwelling (top panel) and annoyance with WTN (lower panel). Annoyance reflects the percentage of participants reporting to be either very or extremely (i.e. highly) bothered, disturbed or annoyed by WTN while at home. Results are shown as a function of modelled outdoor A-weighted WTN levels for wind speeds of 8 meters/second at 10 metre heights, for favourable propagation conditions. * 0.01< P ≤0.05; **0.001< P ≤0.01.

3.5 Objectively measured results

3.5.1 Measures associated with stress

Hair cortisol, blood pressure and resting heart rate measures were applied in addition to the PSS to provide a more complete assessment of the possibility that exposure to WTN may be associated with physiological changes that are known to be related to stress (Russell et al. 2012; Stansfeld and Marmot, 2002).

Cortisol is a well-establish biomarker of stress (Sapolsky et al. 2000), which is traditionally measured from blood and/or saliva. However, measures from blood and saliva reflect short term fluctuations in cortisol and are influenced by many variables including time of day, food consumption, body position, brief stress, etc., that are very difficult to control for in an epidemiological study (Broderick et al. 2004; Edwards et al. 2001; Hennig et al. 2000). To a large extent, such concerns are eliminated through measurement of cortisol in hair samples as cortisol incorporates into hair as it grows. With a predictable average growth rate of 1 cm per month (Wennig, 2000), measurement of cortisol in hair makes it possible to retrospectively examine months of stressor exposure. Therefore cortisol is particularly useful in evaluating the potential impact that long term exposure to WTN has on one of the primary biomarkers linked to stress (Russell et al. 2012).

An excerpt from the final multiple linear regression analysis for hair cortisol and scores on the PSS is presented in Table III. Other variables found to be related to PSS scores or cortisol concentrations included age, gender, incomes, BMI, age, smoking status, hair treatment, audibility of other noise sources, migraines, dizziness, chronic pain and diagnosed sleep disorders (data not shown).

Table III. Multiple linear regression models for perceived stress and hair cortisol (excerpt)

		Perceived Stress Scale		Hair cortisol (ng/g)	
Variable	Groups in Variable	LSM (95% CI)[a]	p-value[c]	LSGM (95% CI)[b]	p-value[c]
		(R^2=0.21, N=987)*		(R^2=0.14, N=528)*	
WTN levels (dBA)	<25	13.67 (11.88, 15.46)	0.8614	150.54 (96.94, 233.77)	0.5416
	25−<30	13.84 (11.92, 15.75)		182.20 (118.52, 280.10)	
	30−<35	13.18 (11.69, 14.67)		191.12 (135.63, 269.33)	
	35−<40	13.15 (11.75, 14.55)		181.63 (132.24, 249.48)	
	40−46	13.48 (12.03, 14.92)		160.25 (115.70, 221.96)	

*Overall R^2 values for the full model. For presentation purposes, only results obtained related to WTN levels are shown. [a] LSM, least squares mean and 95% confidence interval (CI) as determined by the multiple linear regression model; [b] LSGM least square geometric mean and 95% CI; [c] p-value for the parameter in the model after adjusting for all other parameters in the multiple linear regression model.

Hair cortisol was positively correlated with the PSS scores (Pearson r=0.13, p=0.0007) regardless of WTN exposure. When examining each of the WTN categories, a positive

correlation between PSS and hair cortisol is significant only in the following WTN categories: 25−<30 dB (r=0.35, p=0.0137) and 40−46 dB (r=0.20, p=0.0270). Nevertheless, in fitting a regression line relating hair cortisol to PSS and accounting for WTN exposure and province, the slope is positive and significant (slope=0.02, SE=0.01, p=0.0008). This indicates that higher levels of PSS are correlated with higher levels of hair cortisol. Similarly, while self-reported high blood pressure (hypertension) was associated with higher measured blood pressure, no statistically significant association was observed between measured blood pressure, or resting heart rate, and WTN exposure (Table IV).

Table IV. Multiple linear regression models for resting blood pressure and heart rate (excerpt)

		Systolic Blood Pressure		Diastolic Blood Pressure		Heart Rate	
Variable	Groups in Variable	LSGM (95% CI)[a]	p-value[b]	LSGM (95% CI)[a]	p-value[b]	LSGM (95% CI)[a]	p-value[b]
		(R^2=0.23, N=810)*		(R^2=0.19, N=815)*		(R^2=0.11, N=990)*	
WTN Levels (dB)	<25	113.38 (109.17, 117.76)	0.4990	67.98 (64.90, 71.21)	0.5006	68.24 (64.98, 71.66)	0.5223
	25−<30	116.82 (112.36, 121.45)		70.20 (67.01, 73.55)		70.59 (67.38, 73.95)	
	30−<35	116.53 (113.13, 120.03)		69.92 (67.26, 72.70)		69.72 (67.17, 72.37)	
	35−<40	115.30 (112.17, 118.52)		69.66 (67.11, 72.30)		69.56 (67.21, 71.99)	
	40−46	116.25 (112.83, 119.77)		70.34 (67.71, 73.06)		70.71 (68.20, 73.32)	

*Overall R^2 values for the full model. For presentation purposes, only results obtained related to WTN levels are shown. [a] LSGM least square geometric mean and 95% CI; [b] p-value for the parameter in the model after adjusting for all other parameters in the multiple linear regression model.

3.5.2 Actigraphy measured sleep outcomes

Sleep was measured using the Actiwatch2™, which is a compact wrist-worn activity monitor that resembles a watch. This device has advanced sensing capabilities to accurately and objectively measure activity and sleep information over a period of several days. This device is considered to be a reliable and valid method of assessing sleep in non-clinical situations (Ancoli-Israel et al. 2003; Sadeh 2011). The following measured sleep impacts were considered: sleep latency (how long it took to fall asleep); wake time after sleep onset (the total duration of awakenings); total sleep time; the rate of awakening bouts (calculates how many awakenings occur as a function of time spent in bed); and sleep efficiency (total sleep time divided by time in bed).

Sleep efficiency is especially important because it provides a good indication of overall sleep quality (Ancoli-Israel et al. 2003). Sleep efficiency was found to be very high at 85% and statistically influenced by gender, body mass index (BMI), education and caffeine consumption.

The rates of awakening bouts, total sleep time or sleep latency were further found in some cases to be related to: age, marital status, closing bedroom windows, caffeine consumption, BMI, physical pain, having a stand-alone air conditioner in the bedroom, self-reports of restless leg syndrome and being highly annoyed by the blinking lights on wind turbines.

While it was found that many variables had a significant impact on measured sleep, calculated outdoor WTN levels near the participants' dwelling was not found to be associated with any of the sleep endpoints measured with actigraphy (data not shown).

4. CONCLUSIONS AND DATA AVAILABILITY

Including both self-reported and physically measured health effects together provides a more complete overall assessment of the potential impact that exposure to wind turbines may have on health and well-being. The overall conclusion to emerge from the study findings is that the study found no evidence of an association between exposure to WTN and the prevalence of self-reported or measured health effects beyond annoyance. Collectively, the findings related to annoyance suggest that health and well-being effects may be partially related to activities that influence community annoyance, over and above exposure to WTN. Therefore, efforts that aim to identify and mitigate high levels of annoyance with wind turbines may have benefits that go beyond annoyance.

Detailed descriptions of the above results will be submitted for peer review with open access in scientific journals and should only be considered final following publication. All publications by Health Canada related to the study will be identified on the Health Canada website http://www.hc-sc.gc.ca/ewh-semt/noise-bruit/turbine-eoliennes/scientific-journal-publications-scientifique-eng.php.

Raw data originating from the study is available to Canadians, other jurisdictions and interested parties through a number of sources: Statistics Canada Federal Research Data Centres, the Health Canada website (acoustical data), open access to publications in scientific journals and conference presentations. Plain language abstracts outlining the research and identifying the scientific journals where papers can be found will further be published to the Departmental website.

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