Wind Turbines: A Brief Health Overview

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Disclosures

Presenter Affiliations
- Centers for Disease Control and Prevention, Epidemic Intelligence Service
- United States Public Health Service
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- University of Wisconsin, School of Medicine and Public Health

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Conflicts of Interest: None
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Resources Used

- Peer-reviewed literature
- National/International Guidelines
- Other Health Department Reviews
- Surveys conducted
- Personal Communication
Objectives

- Present an overview of how to assess epidemiological studies
- Present a brief review of current topics relating to wind energy & human health
- Outline a strategy for going forward based on credible medical and public health science
Outline

- Human health issues
  - Shadow flicker
  - Noise and human health
  - Low frequency sound & Infrasound
  - Wind turbine noise and human health
- Sleep disturbance
- Studies of wind turbine noise and health
- What can epidemiology tell us?
- WHO guidelines
- Strategies for going forward
Role of Public Health Science

- Population disease prevention
- Population health promotion
- Using credible science to make population health-related recommendations
When is it appropriate to use these terms?

- Cause
- Does not cause
- Leads to
- Associated with
- At risk for
- Odds of
CDC Definition of Peer Review

- A process that includes an independent assessment of the technical or scientific merit of research by peers who are scientists with knowledge and expertise equal to that of the researchers whose work they review and who provide written assurance that their reviews are free of any real or perceived conflicts of interest.
Areas of Agreement

- Decisions about wind turbine development should be based on credible scientific evidence
- Wind turbines generate sound
- Wind turbines in close proximity to homes have been perceived as a health threat by some
Human Health Concerns
Potential Health & Safety Issues

- Shadow flicker
- Sound emissions and noise concerns
- Icing issues in northern climates
- Turbine blade and structural failure
- Construction injuries
- Wildlife concerns
- Flora and fauna impact
- Groundwater contamination
Shadow Flicker
What is Shadow Flicker?

- Moving shadows from rotating wind turbine blades
- Similar to flicker experienced when driving

Shadow Flicker

- Wind turbine rotor frequencies
  - Average 0.6–1.0 Hz
  - Max 3 Hz (at 60 rpm)
  - National Research Council: “Harmless to humans”

- Photosensitivity epilepsy
  - 1/4,000 individuals
  - Sunlight, TV are common precipitants

- Flickering light most likely to trigger seizures
  - 5–30 Hz

NRC, 2007; National Epilepsy Foundation; Harding, 2008
Shadow Flicker

- Interruption of sunlight by helicopter blades has caused seizures
- 2 unconfirmed reports of seizures due to shadow flicker
- At ≤3 Hz risk is 1.7 per 100,000 photosensitive population (1.7 per 400 million persons)
- At typical wind turbine frequencies (0.6–1.0 Hz) shadow flicker is primarily an issue of annoyance.

Harding, 2008
Noise and Human Health
Decibel Rating

- Logarithmic unit of measurement that expresses the magnitude of sound intensity relative to a reference level (hearing threshold)
- 10 dB = 10x more intense than 0 dB
- 20 dB = $10^2$ (100x) more intense than 10 dB
- 30 dB = $10^3$ (1000x) more intense than 20 dB

http://vancouver.ca/engsvcs/projects/soundsmart/images/dbScale2-2-2.jpg
Health Effects of Chronic Noise Exposure

- Hearing impairment
- Hypertension
- Ischemic heart disease
- Sleep disturbance
- National Institute for Occupational Safety and Health
  - Recommended exposure level (REL) for occupational noise exposure
    - 85 dBA as an 8-hr time weighted average
    - Exposures ≥ this level are hazardous

## Observational Thresholds of Health Effects

<table>
<thead>
<tr>
<th>Effect</th>
<th>Exposure type</th>
<th>Measure*</th>
<th>dB</th>
<th>Location of assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hearing Impairment</td>
<td>Environmental</td>
<td>$L_{eq}$ (24 hr avg)</td>
<td>70</td>
<td>Indoors</td>
</tr>
<tr>
<td></td>
<td>Occupational</td>
<td></td>
<td>75</td>
<td></td>
</tr>
<tr>
<td>Hypertension</td>
<td>Environmental</td>
<td>$L_{dn}$ (24 hr avg)</td>
<td>70</td>
<td>Outdoors</td>
</tr>
<tr>
<td></td>
<td>Occupational</td>
<td>$L_{eq}$ (24 hr avg)</td>
<td>&lt;85</td>
<td>Indoors</td>
</tr>
<tr>
<td>Ischemic Heart Disease</td>
<td>Environmental</td>
<td>$L_{eq}$ (24 hr avg)</td>
<td>70</td>
<td>Outdoors</td>
</tr>
<tr>
<td>Annoyance</td>
<td>Environmental</td>
<td>$L_{dn}$ (24 hr avg)</td>
<td>42&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Outdoors</td>
</tr>
<tr>
<td></td>
<td>Occupational</td>
<td>$L_{eq}$ (24 hr avg)</td>
<td>Industry &lt;85 Office &lt;55</td>
<td>Indoors</td>
</tr>
<tr>
<td>Performance</td>
<td>School</td>
<td>$L_{eq}$ (avg during school day)</td>
<td>70</td>
<td>Outdoors</td>
</tr>
<tr>
<td></td>
<td>Occupational</td>
<td>$L_{eq}$ (avg during school day)</td>
<td>70</td>
<td></td>
</tr>
<tr>
<td>Disturbance of Sleep pattern</td>
<td>Sleep</td>
<td>$L_{eq}$ (overnight avg)</td>
<td>&lt;60</td>
<td>Outdoors</td>
</tr>
<tr>
<td>Awakening</td>
<td>Sleep</td>
<td>SEL</td>
<td>55</td>
<td>Indoors</td>
</tr>
<tr>
<td>Sleep Quality</td>
<td>Sleep</td>
<td>$L_{eq}$ (overnight avg)</td>
<td>40</td>
<td>Outdoors</td>
</tr>
<tr>
<td>Mood Next Day (sleep disturbance)</td>
<td>Sleep</td>
<td>$L_{eq}$ (overnight avg)</td>
<td>&lt;60</td>
<td>Outdoors</td>
</tr>
</tbody>
</table>

<sup>a</sup> The information contained in Table 1 was derived from Passchier-Vermeer and Passchier (2000).

<sup>b</sup> Noise levels presented in this table are presented as an equivalent sound level ($L_{eq}$) measured over a period of time and day-night level ($L_{dn}$) which measures sound level over 24 hours with sound levels during the night. A sound exposure level (SEL) is the equivalent sound level of an event measured over 1 second.

<sup>#</sup> The dB level causing annoyance is approximately 12 dB lower for impulse noise.

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Passchier-Vermeer, 2000; www.publichealthmdc.com
Modifiers of Effects of Sound on Humans
Levels of Noise Exposure

- **High level noise exposure (>70 dBA)**
  - Evidence of direct physiological effects
  - Hearing loss
  - Altered function of cardiovascular and endocrine systems

- **Moderate level noise exposure (30–50 dBA)**
  - Effects influenced by noise sensitivity
  - Perceived control over exposure is important predictor of adverse effects

Staples SL, 1997
Noise Sensitivity

- Stable personality trait
- Evaluative rather than sensory aspects of auditory processing
- Strong predictor of noise-induced self-reported sleep disturbances
- Associated with negative affectivity

Schreckenberg, 2010; Ellermeier, 2001; Miedema, 2003; van Kamp, 2004
Noise Annoyance

- Reflects quality of life
- Feeling of displeasure, nuisance, disturbance, or irritation caused by a specific sound

Ouis, 2001; Miedema, 2007
Reactions to Noise

- Complex

- Self-reported physiological reactions correlated with psychological reactions
  - Expectation of increases in noise can lead to increased self-reported symptoms, even in the absence of actual increases in noise

Hatfield, 2001
Noise & Health — Conclusions

- Chronic exposure to high levels of sound
  - Hearing loss
  - Altered physiological processes
- Long-term health effects of chronic exposure to low level sound not well characterized
- Noise sensitivity is important determinate of responses to noise
- Response to moderate levels of sound affected by cognitive appraisal of sound source
Infrasound & Low Frequency Sound
Infrasound & Low Frequency Noise (LFN)

- **Low frequency sound**: 10–200 Hz
  - Near the bottom of human perception
  - Heart and lung sounds are low-frequency, low amplitude

- **Infrasound**
  - <20 Hz
  - Audible at high levels 90–110 dB
  - Threshold of aural pain 120 dB
  - Undervalued in dBA measurements
  - Perceived as a mixture of auditory and tactile sensations
  - Ubiquitous in the environment
    - Waves on seashore
    - Ambient air turbulence

Schust, 2004; Leventhall, 2004; NIEHS, 2001
Infrasound, LFN & Health

- World Health Organization — *Guidelines for Community Noise, 2000*
  - “The evidence on low-frequency noise is sufficiently strong to warrant immediate concern….Low-frequency noise may also produce vibrations and rattles as secondary effects. Health effects due to low-frequency components in noise are estimated to be more severe than for community noises in general.”

- National Research Council — *Impacts of Wind-Energy Development on Humans, 2007*
  - Effects of low-frequency vibration on humans are not well understood, and that there are opposing views on the subject

- NIEHS — *Infrasound Toxicological Summary, 2001*
  - “In summary, though a number of biological effects have been reported that are attributed to infrasound exposure in experimental settings, any assessment of potential adverse human health effects resulting from environmental infrasound exposure is hampered by numerous gaps in our current knowledge.”

- Based on research at high (audible) dB levels

WHO, 2000; NRC, 2007; NIEHS, 2001
Infrasound, LFN, & Wind Turbines

- Wind turbines below hearing threshold (90–110 dB at infrasound frequency)
- May become audible with unusually turbulent inflow air
- Evidence does not support conclusion that infrasound/LFN below the hearing threshold causes long term adverse health outcomes
- Characteristic “swooshing” sound at 500–1000 Hz

Infrasonic and Low Frequency Threshold

Modified from Source: Leventhall (2007)

Leventhall, 2004; Leventhall, 2007; Rogers, 2006; NIEHS, 2001
Vibroacoustic Disease (VAD)

- Characterized by connective tissue thickening, depression, irritability, aggressiveness, and decreased cognitive skills
- First described in aircraft technicians exposed to low-frequency noise (LFN) at high levels
- Included persons chronically exposed to environmental LFN based on a limited case series
- No controls
- Multiple confounders
- Endogenous sources of LFN unaccounted for
- Theory proposed by single group of researchers
  - Findings disputed by 2 other groups of researchers

Castelo Branco NAA, Alves-Pereira M, 2004
von Gierke, 2002; Jensen, 2008
Infrasound & LFN — Conclusions

- Current evidence does not support causal link between inaudible infrasound or LFN and adverse health effects
- Infrasound and LFN from wind turbines is nearly always below the hearing threshold
- Vibroacoustic disease is a theory, not an established medical diagnosis
Wind Turbine Noise and Human Health
Visceral Vibratory Vestibular Disturbance (VVVD)

- The physical sensations of quivering, jitteriness, or pulsation accompanied by acute anxiety, fearfulness, or agitation, irritability, sleep disturbance, and episodes of tachycardia.

- Signs/symptoms
  - Non-specific
  - Seen in many stress reactions

- VVVD is not an accepted phenomenon in medical community

Pierpont, 2009
“Wind Turbine Syndrome”

- **Case series**
  - Limited to persons who attributed symptoms to wind turbine exposure
  - All self-reported data, no medical record review

- **Hypothesized syndrome**
  - Lack case definition or diagnostic criteria

- **Symptoms**
  - Non-specific

- **Proposed pathophysiology**
  - Infrasonic activation of vestibular system and internal organs

- **Conclusion: “Wind turbines cause wind turbine syndrome”**

Pierpont, 2009; Todd, 2009
Sleep Disturbance
Chronic Sleep Disturbance

- Very common
- Complex and multifactorial
- Perceived disturbance ≠ measured disturbance
- Often sign of underlying psychological or medical disease
- Should be evaluated by healthcare provider
- Assumptions of environmental causes may lead to a serious medical causes of sleep disturbance going undiagnosed

Michaud, 2007
Sleep Disturbance

- Numerous types of sleep disorders
- Measurable factors
  - Polysomnography (PSG) – measurement of a person’s physiology during sleep
    - Brain activity
    - Muscle activity
    - Heart rhythm
    - Eye movements
    - Respiratory airflow and effort
    - Blood oxygen level
  - Sleep logs
  - Validated questionnaires
Sleep Disturbance

- Many factors influence subjective evaluations of sleep quality
- Health consequences of instantaneous effects are unclear
- Lack of a clear dose-response between noise and sleep disturbance related to complex interactions
  - Noise characteristics
  - Individual sensitivity
  - Context of living environment

Michaud, 2007; Miedema, 2007
Environmental Sleep Disorder

“Sleep disturbance due to a disturbing environmental factor that causes a complaint of either insomnia or excessive sleepiness”

Diagnosis requires

- Temporally associated with measurable stimulus
- Physical rather than the psychological properties of environmental factors causative
- Removal of the responsible factors results in return to normal
- Present for >3 weeks
- Sleep study demonstrates normal sleep
- No underlying mental or medical disorder
- Symptoms do not meet criteria for any other sleep disorder

American Academy of Sleep Medicine, 2001; WHO Night Noise Guidelines
Sleep Insufficiency in the U.S.

Age-adjusted percentage of adults reporting insufficient rest or sleep during the preceding 30 days, by age

Adapted from MMWR. 2009;58(42):1175-1179.
Factors Affecting Sleep

Frequency of Concerns/Events Disturbing Sleep in Past Month

- Net: Any 16% 18% 34%
- Net: Economic concerns* 12% 15% 27%
- Personal financial concerns* 7% 9% 16%
- The U.S. economy* 5% 10% 15%
- Health-related concerns 6% 7% 14%
- Employment concerns* 4% 6% 10%
- Concerns about personal relationships 2% 6% 9%
- Healthcare costs* 3% 5% 8%
- The war in Iraq or Afghanistan 2% 4% 6%
- Global warming/Environment 2% 2% 3%
- Threat of terrorism 1% 2% 3%

Base = Total sample (n=1,000)
*Note: This net includes the attributes of personal financial concerns, the U.S. economy, employment concerns and healthcare costs.
Q12

http://www.sleepfoundation.org/
Discussed Sleep Issues with a Healthcare Professional

![Bar Chart]

- Yes: 32%
- No: 68%

Base = Total sample (n=1,000)
DK/Ref = <1%
Q35

[Link: http://www.sleepfoundation.org/]
What can epidemiology tell us?
Descriptive Studies

- Case report
  - Single observation of an unusual disease
  - Least publishable unit in medical literature
- Case-series report
  - Aggregate of individual cases
- Example

Descriptive Studies

- **Uses**
  - Hypothesis development

- **Pitfalls**
  - Absence of a clear, specific, and reproducible case definition
  - Interpretations that overstep the data

Analytic Studies

- Cross sectional studies
  - Example: U.S. Census
  - Measure exposure and disease/symptoms at the same time
- Case-control studies
- Cohort studies
Strength of Evidence

- Systematic Review
- Randomized Controlled Trial
- Cohort studies
- Case-Control studies
- Cross sectional studies
- Case Series/Case Reports
- Animal research/Laboratory studies
- Expert opinion without explicit critical appraisal

Outcomes
- Strongest evidence of causal relationship
- Strong evidence of causal relationship
- Risk of disease association with exposure; temporality
- Odds of case being exposed
- Hypothesis generation; Case definition formulation
- Disease pathophysiology hypothesis generation

Adapted from Cebt.net, 2009; Zaccai, 2004; Gordis. Epidemiology, 2nd ed. 2000.
Confounding

Causal Association

Coffee Drinking → Risk of Pancreatic Cancer

Due to Confounding

Coffee Drinking → Risk of Pancreatic Cancer

Smoking

Confounding

Causal Association

Wind turbine noise \(\rightarrow\) Self-reported symptoms

Due to Confounding

Wind turbine noise \(\leftrightarrow\) Stress Anxiety, Anger Annoyance \(\leftrightarrow\) Lack of financial compensation

Effect modifiers

Wind turbine visibility

Self-reported symptoms
Assessing Epidemiological Studies

- Whom is the study about?
- Was the design of the study sensible?
- Was systematic bias avoided or minimized?
- Was the study large enough and long enough to make the results credible?
- Are the results generalizable?

Personal Experience May Affect Objectivity

- Personal experience may compromise objectivity
- In medicine
  - Physicians should not treat themselves or their family
- In studying effects of wind turbines
  - Strong opinions by study participants or researchers can bias results
Conclusions – Epidemiological Methods

- Case series reports help with hypothesis formation

- Failure to adequately account for confounding factors can lead to significant misinterpretations of study results
Studies of Wind Turbine Noise and Health
Studies of Wind Turbine Noise and Health

- **Case series**
  - Pierpont, Nissenbaum, Harry, McMurtry, Phipps
  - No review of medical records
  - Allow only hypothesis formation

- **Cross sectional studies**
  - Denmark (1993, 1994)
  - Sweden (2004, 2007)
  - Netherlands (2008)
  - Self-reported outcomes

- **Case-control studies**: none
- **Cohort studies**: none
Odds of self-reported sleep disturbance significantly higher at levels >45 dBA

Participation inversely associated with self-reported sleep disturbance

<30% of respondents reported sleep disturbance ≥ once/month

Relation between levels of wind turbine sound and self-reported sleep disturbance from wind turbines (only non participants included)

Van den Berg, 2008
Project WINDFARMperception — Annoyance

- Wind turbine sound is relatively annoying
- Respondents more annoyed from wind modern than other noise sources

Relation between sound level $L_{den}$ and percentage highly annoyed residents exposed to that sound, for three transportation noise sources and for wind turbines

Van den Berg, 2008
Conclusions

- No indication sound from wind turbines had an effect on self-reported health measures
  - Exception: sleep at sound >45 dBA

- Primary reported outcome: annoyance
  - Inversely correlated economic benefits
  - Associated with
    - Psychological distress
    - Stress
    - Difficulties falling asleep and sleep interruption
  - “From this study is cannot be concluded whether these health effects [i.e. sleep disturbance and stress] are caused by annoyance or vice versa or whether both are related to another factor.”

Van den Berg, 2008
Factors associated with annoyance
- Living in rural area
- Low background noise areas
- Noise sensitivity
- Negative general attitude towards turbines
- Negative attitude of visual impact
- Turbine visibility

Sound not associated with health or well-being
- Minimally assessed

Noise annoyance associated with sleep quality and negative emotions
Wind Turbine Noise and Human Health — Conclusions

- Statistically significant self-reported sleep disturbance at wind turbine sound levels $>45$ dBA
- Wind turbine sound more annoying than most other environmental noise
- Annoyance strongly associated with noise sensitivity, attitudes towards turbines, and turbine visibility
## WHO Night Noise Guidelines for Europe, 2009

<table>
<thead>
<tr>
<th>Effect</th>
<th>Indicator</th>
<th>Threshold, dB</th>
</tr>
</thead>
<tbody>
<tr>
<td>EEG awakening</td>
<td>L_{Amax,inside}</td>
<td>35</td>
</tr>
<tr>
<td>Changes in sleep structure</td>
<td>L_{Amax,inside}</td>
<td>35</td>
</tr>
<tr>
<td>Waking up at night or early morning</td>
<td>L_{Amax,inside}</td>
<td>42</td>
</tr>
<tr>
<td>Onset of motility</td>
<td>L_{Amax,inside}</td>
<td>32</td>
</tr>
<tr>
<td>Increased average motility</td>
<td>L_{night,outside}</td>
<td>42</td>
</tr>
<tr>
<td>Self-reported sleep disturbance</td>
<td>L_{night,outside}</td>
<td>42</td>
</tr>
<tr>
<td>Use of sedatives</td>
<td>L_{night,outside}</td>
<td>40</td>
</tr>
<tr>
<td>Environmental insomnia</td>
<td>L_{night,outside}</td>
<td>42</td>
</tr>
</tbody>
</table>

Estimated outdoor-indoor average attenuation 21 dB(A)
Applying WHO Guidelines

- Designed to offer guidance based on consensus expert evaluation of evidence in Europe
- Describe lowest noise levels below which no health effects are likely to occur
- Recent change from 45 dBA to 40 dBA $L_{\text{night, outside}}$ based on 2 aircraft noise studies
- Caution should be used in applying conclusions and recommendations to wind turbine noise in U.S.
  - Data largely from aircraft noise studies
  - Nearly all studies conducted in Europe
  - No data regarding sleep and wind turbine noise

WHO, 2009
Where do we go from here?
How to Study Health Effects

- Primary concern is exposure to wind turbines
- Most commonly reported complaint is sleep disturbance
- Other complaints include headache, nausea, vibration sensations, etc.
- There is no diagnostic medical test
- Self-reported symptoms are subjective and prone to bias
Value of an Epidemiological Study

- No validated questionnaire
  - Essential when evaluating subjective symptoms
  - Does a survey measure what it intends to measure?
- No measurable outcomes (except for sleep)
- Potential epidemiological study
  - Subject to large amount of reporting bias
  - Multiple confounding factors
Value of an Epidemiological Study

- No study design that would enable assessment of association between wind turbines and measurable health outcomes
Sleep Disturbance — Hypothetical Study

- Experimental/Clinical design
- Evaluate objective sleep parameters
- Measure exposure levels at different dBA levels
- Assess measurable sleep parameters in response to different “doses” of wind turbine sound
- Would assess dose-response and temporality
Concepts of Medical Research

- Assuming reported symptoms are solely related to an exogenous source (e.g. wind turbines) without evaluating for known causes of these symptoms is poor medical practice.
- Persons with sleep problems should be medically evaluated.
- Symptoms of sleep disturbance, vertigo, tinnitus, anxiety, etc. may represent serious underlying medical conditions.
Patient reports symptoms to MD

MD collects data

MD excludes known causes of patient’s symptoms

MD reports findings to local health department (LHD)

LHD gathers additional information

Investigation initiated if significant public health threat

LHD sends data to Wisconsin Division of Public Health (WDPH)

WDPH analyzes data
General Conclusions

- Evidence does not support the conclusion that wind turbines cause or are associated with adverse health outcomes.

- Current evidence is not compelling enough to invoke the precautionary principle.
General Conclusions

- Gaps remain in our knowledge of the impact that wind energy may have on human health
  - Potential positive and potential negative impacts
- Defined broadly enough, “health effects” would include most of the human experience
- Annoyance is not a disease
  - Quality of life issue
  - Does not necessitate public health intervention
  - Can be a legitimate factor to consider in wind turbine siting
Recommendations

- Encourage concerned individuals to report symptoms or illness to a healthcare provider
- Encourage health officials to continue to assess new evidence as it becomes available
- Involving affected individuals in siting process