

Wind Turbines: A Brief Health Overview

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Disclosures

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■ Related outside activities: None

■ Conflicts of interest: None

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Disclaimers

- **The findings and conclusions in this report are those of the author and do not necessarily represent the official position of the Centers for Disease Control and Prevention**
- **The findings and conclusions in this report do not necessarily represent the official position of the Wisconsin Department of Health Services**
- **The findings and conclusions in this report reflect a review of population-level concepts, and are not intended to confirm or deny the credibility of any individual's personal account of the impact that wind turbines may have had on their lives**



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**

Ice Throw and Ice Shed

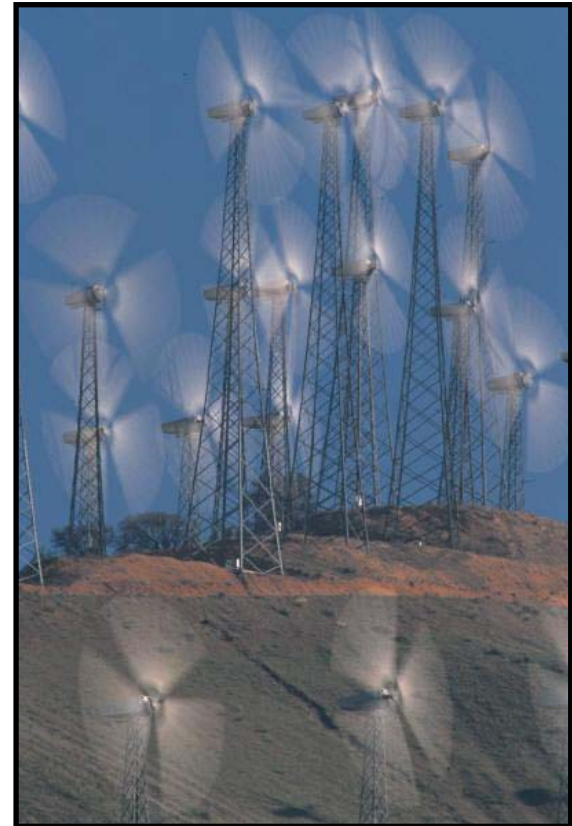
- Ice may form on wind turbines
- Ice fragments can be thrown from moving turbine blades or break loose and fall to the ground
- Observations from Ontario, Canada
 - 1995–2001
 - 1,000 inspections of a single wind turbine
 - 13 occasions of ice build-up
 - Fragments within 100 m of the turbine
- Calculated risk of ice striking
 - Fixed dwelling 300m from turbine: 1 per 500,000 years
 - Vehicles on a road at 200m from turbine: 1 per 260,000 years
 - Individual walking in area 50–300m from turbine: 1 per 1.38×10^8 years
- No non-industry-sponsored assessments available
- Remains a theoretical health problem in that there have been no known reports of humans being injured from this phenomenon



Shadow Flicker

What is Shadow Flicker?

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



http://www.goodhuewindtruth.com/uploads/Wind_Turbine_Health_Effects.pdf

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

Shadow Flicker

- Interruption of sunlight by helicopter blades has caused seizures
- 2 unconfirmed reports of seizures due to shadow flicker
- No epileptogenic risk to observers looking towards horizon except when standing closer than 1.2x the total turbine height
- 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.

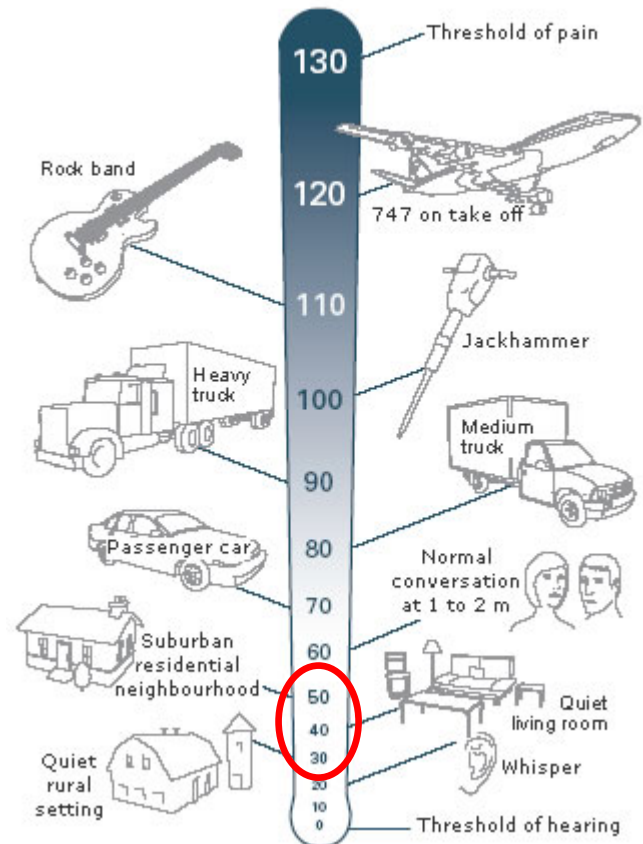


Noise and Human Health

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

DECIBEL SCALE (dBA)



<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 \geq this level are hazardous

Observational Thresholds of Effects

Effect	Exposure type	Measure	dB	Location
MEASURABLE				
Hearing impairment	Environmental	L_{aeq} (24 hr avg)	70	Indoors
	Occupational		75	
Ischemic heart disease	Environmental	L_{aeq} (24 hr avg)	70	Outdoors
Hypertension	Environmental	L_{dn} (24 hr avg)	70	Outdoors
	Occupational	L_{aeq} (24 hr avg)	<85	Indoors
Awakening	Sleep	SEL	55	Indoors
Heart rate	Sleep	SEL	40	Indoors
Disturbance of sleep pattern	Sleep	L_{aeq} (overnight avg)	<60	Outdoors
SUBJECTIVE				
Sleep quality	Sleep	L_{aeq} (overnight avg)	40	Outdoors
Annoyance	Environmental	L_{dn} (24 hr avg)	42	Outdoors
	Occupational	L_{aeq} (24 hr avg)	Industry <85 Office <55	Indoors



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

Noise Sensitivity

- **Stable personality trait**
- **Evaluative rather than sensory aspects of auditory processing**
- **Strong predictor of noise-induced self-reported sleep disturbances**
- **Noise sensitivity often more important factor in reported sleep disturbance than noise level**
- **Associated with negative affectivity**

Noise Annoyance

- May reflect quality of life
- Feeling of displeasure, nuisance, disturbance, or irritation caused by a specific sound
- Increases with fear of danger from the noise source, sensitivity to noise, belief that authorities can control the noise, awareness of non-noise impacts of the source, and the belief that the noise source is not important
- Is annoyance associated with long-term adverse health effects?
 - Chronic annoyance may contribute to stress-related illness after long term exposure,
 - Unknown to what extent chronic annoyance can actually be measured,
 - There is no consensus on how chronic annoyance and stress-related illness might be quantitatively related

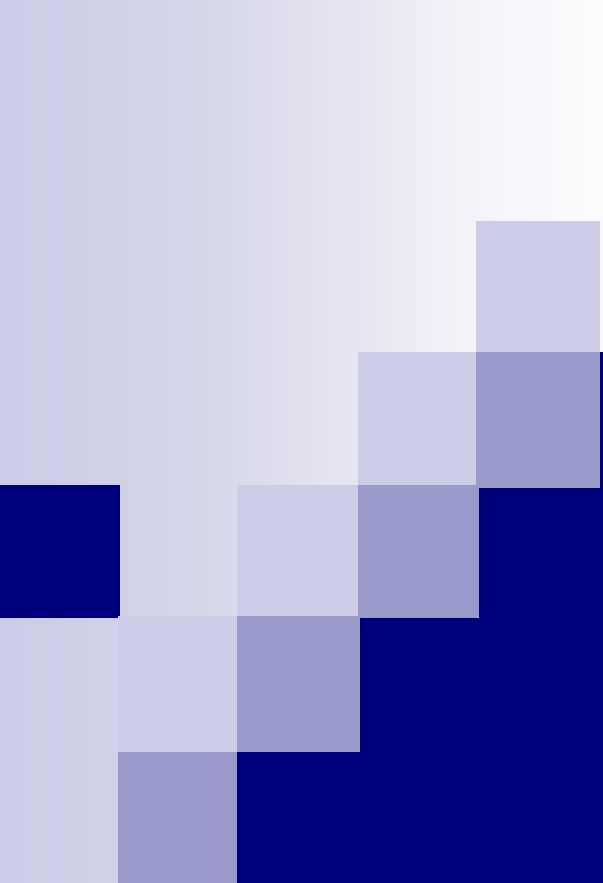
Reactions to Noise

- **Mediated by auditory and evaluative processes**
- **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**



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

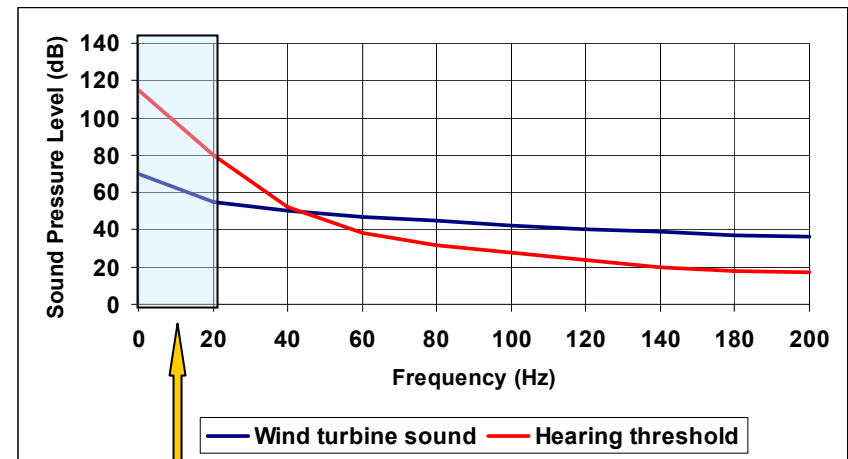
Infrasound, LFN & Health

- **World Health Organization — *Guidelines for Community Noise, 1999***
 - “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**

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 and most annoying “swooshing” sound at 500–1000 Hz

Infrasonic and Low Frequency Threshold



Modified from Source: Leventhall (2007) and Rogers (2006)

Infrasound

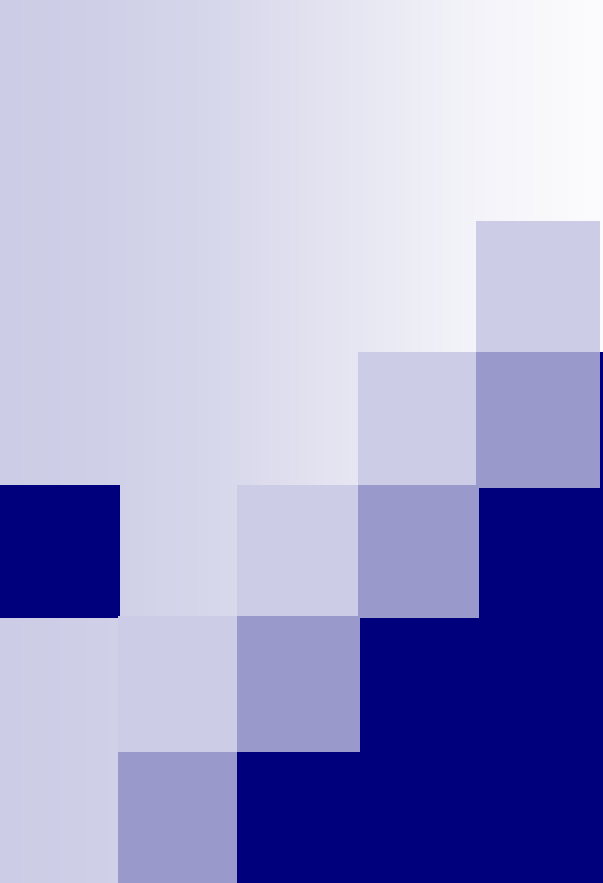
Vibroacoustic Disease (VAD)

- 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



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**

“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 within body cavities
- ☐ Based in part on a study by Todd et al., who has since clarified that his study results do not provide the evidence to support this hypothesis

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

- ☐ Use of the term “cause” is not consistent with the study design



Sleep Disturbance

Chronic Sleep Disturbance

- **Definition of Insomnia: the subjective perception of difficulty with sleep initiation, duration, consolidation, or quality that occurs despite adequate opportunity for sleep, and that results in some form of daytime impairment**
 - “Insomnia” can refer to a symptom or a sleep disorder
- **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**

Evaluation of Sleep Disturbance

- 81 different disorders recognized by American Academy of Sleep Medicine
- Evaluation starts with comprehensive history and physical exam by a healthcare provider
- 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

Reasons for Having Sleep Problems Evaluated

- American Academy of Sleep Medicine recommends seeking medical advice if sleep deprivation has compromised your daytime functioning for more than a month
- May be a symptom of underlying or comorbid medical problems
 - Medical: obstructive sleep apnea, congestive heart failure, arthritis, chronic pain syndromes, etc.
 - Psychiatric: major depression, generalized anxiety disorder, Alzheimer disease and other dementias, etc.
 - Other: menopause, substance use, medication side effects etc.
- Amenable to treatment
- Untreated, can lead to significant problems
 - Safety (to oneself and others)
 - Decreased productivity
 - Worsening comorbid conditions

Sleep Disturbance and Noise

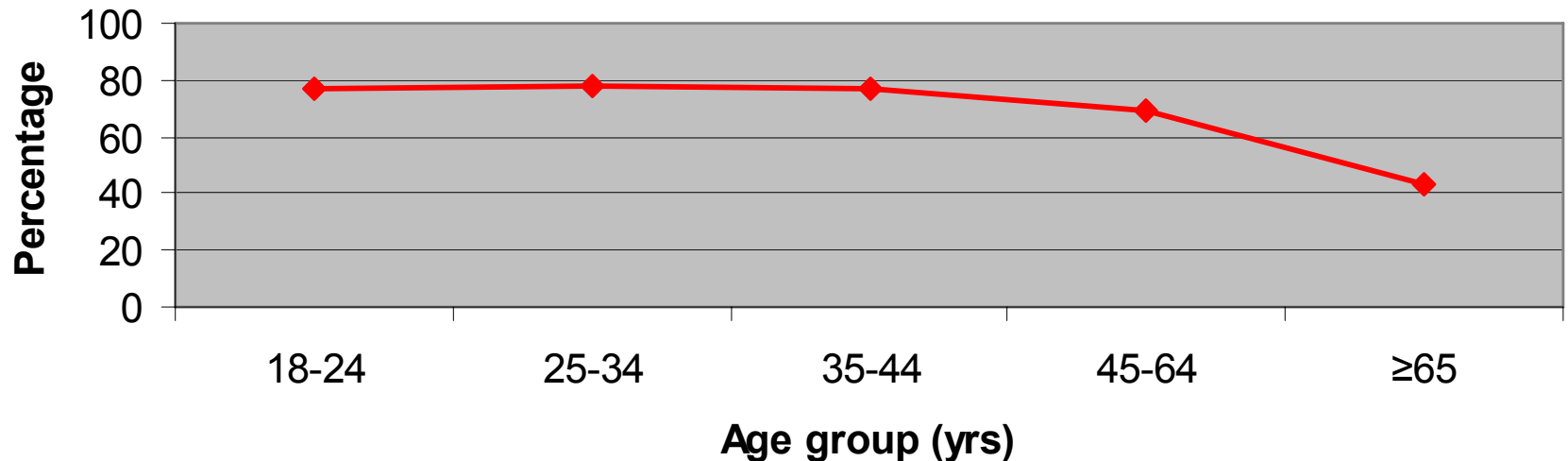
- Many factors influence subjective evaluations of sleep quality
- Health consequences of instantaneous effects are unclear
- Important to distinguish between endogenous (anxiety, stress, etc.) and exogenous (noise) reasons for sleep disturbance
- Few quality studies with highly variable results and assessments makes it difficult to make evidence-based recommendations
- Lack of a clear dose-response between noise and sleep disturbance related to complex interactions
 - Noise characteristics
 - Individual sensitivity
 - Context of living environment

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

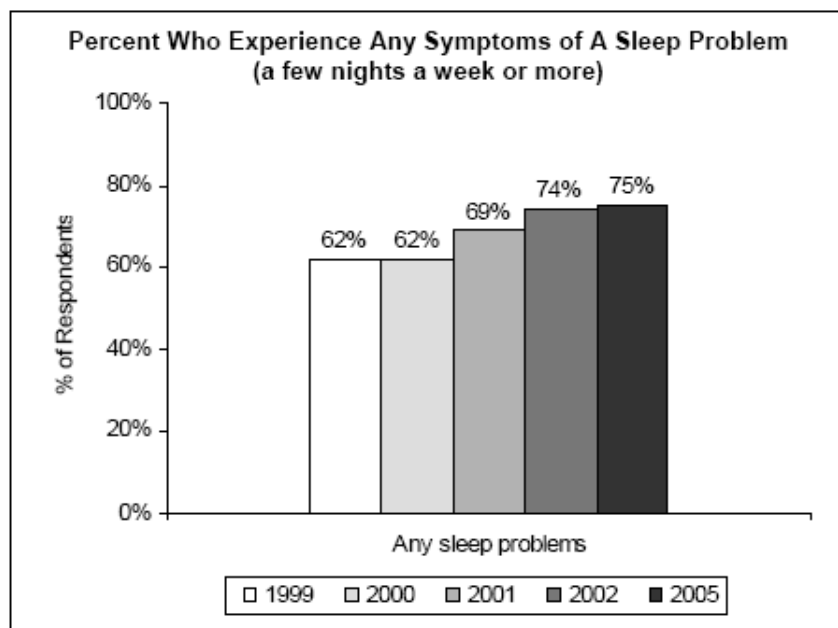
Sleep Insufficiency in the U.S.

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



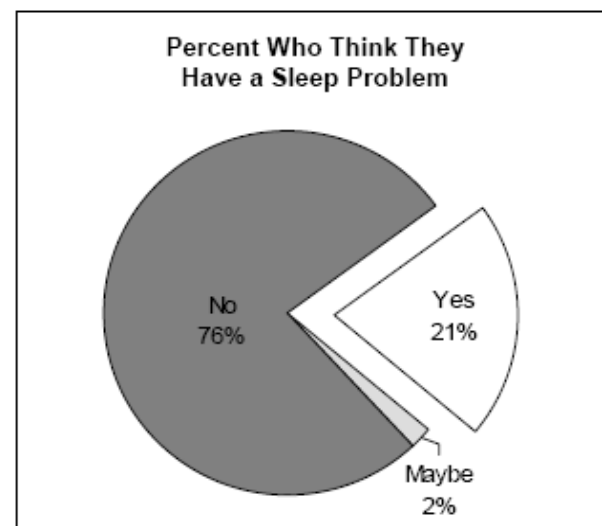
Adapted from MMWR. 2009;58(42):1175-1179.

Symptoms of Sleep Problems vs Thinking Sleep is a Problem



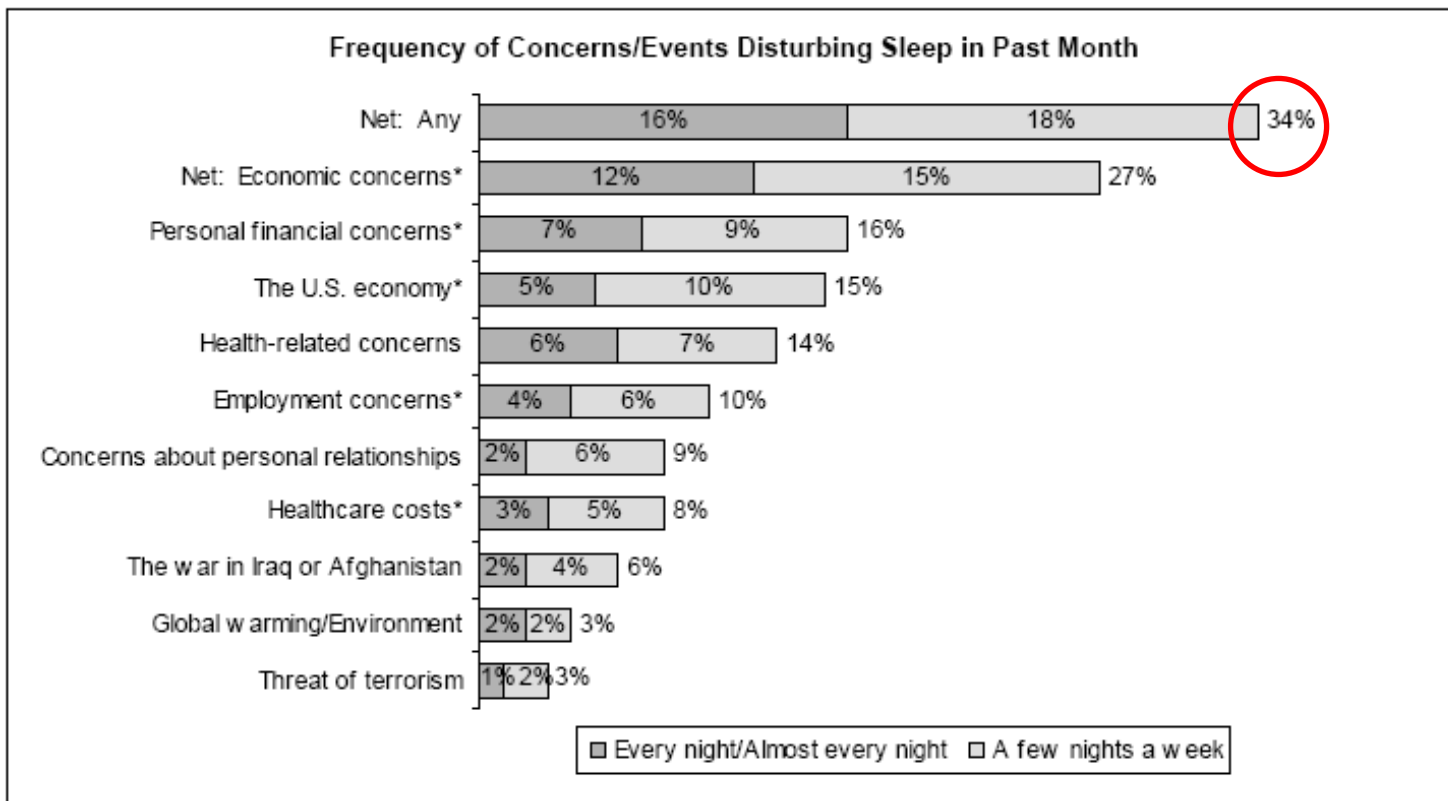
Base = Total sample (n=1,506)

Note: Any sleep problem includes any symptoms of insomnia, snoring, sleep apnea, restless legs syndrome.



Base = Total sample (n=1,506)
Don't know/Not sure/Refused = 1%

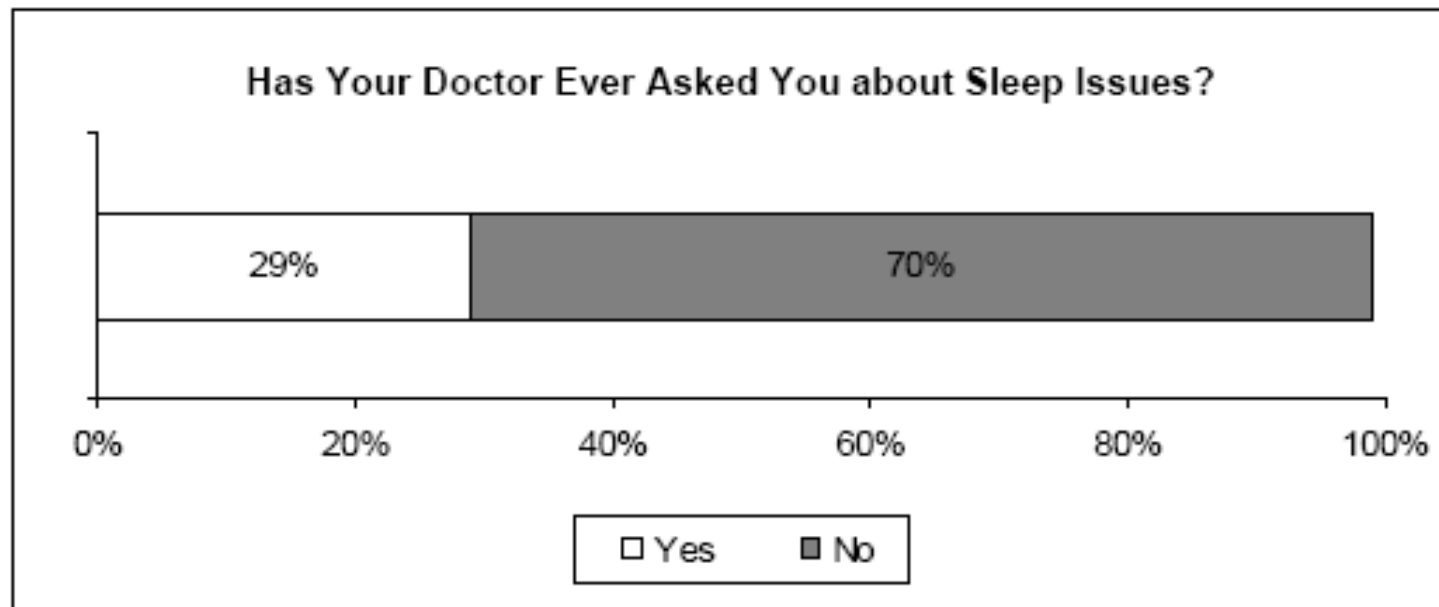
Factors Affecting Sleep



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.

Discussed Sleep Issues with a Healthcare Professional



Base = Total sample (n=1,506)

Don't know = 1%



**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**
 - Presenting signs
 - Presenting symptoms
 - Medical history
 - Diagnostic tests
 - Blood tests
 - EKGs, x-rays, etc.
 - Discussion of how the case is similar or different to other patients

Descriptive Studies

■ Uses

- Hypothesis development

■ Pitfalls

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

Analytic Studies

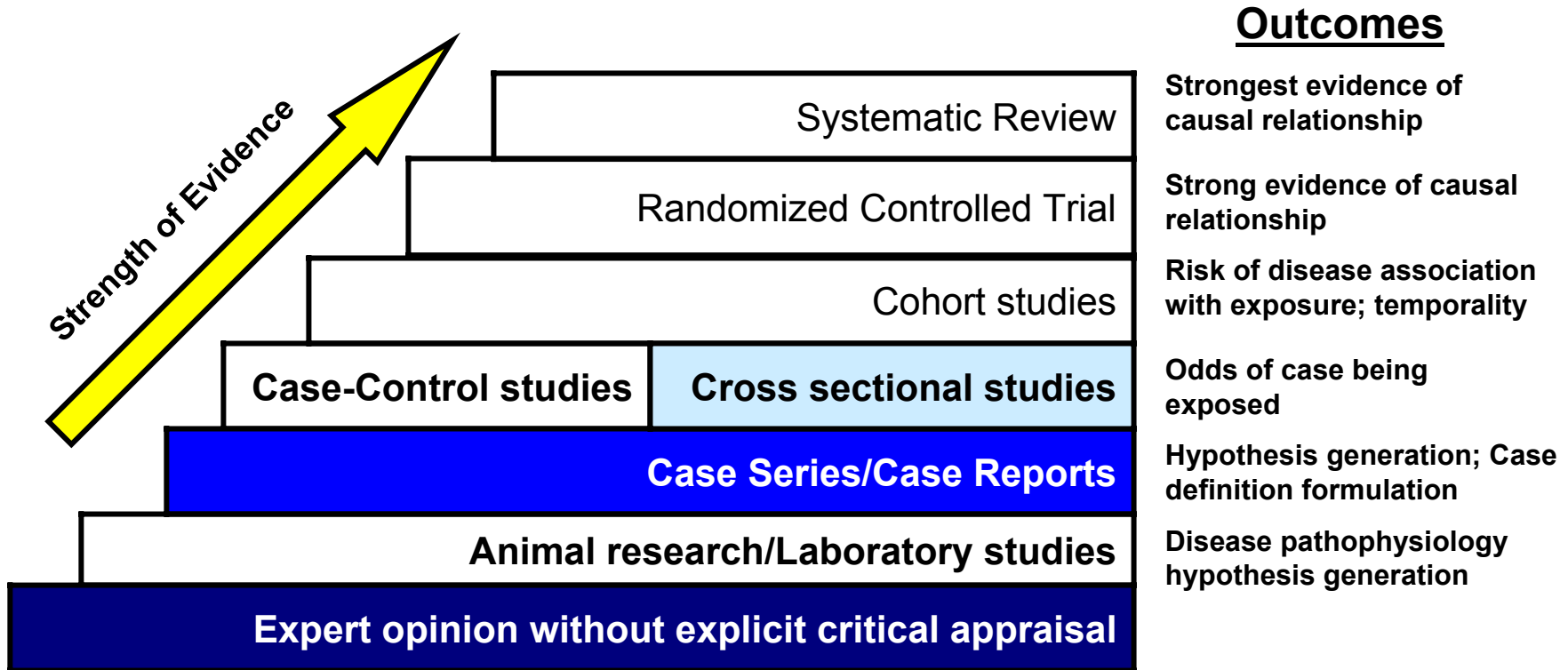
- **Cross sectional studies**

- ☐ Example: U.S. Census
- ☐ Measure exposure and disease/symptoms at the same time

- **Case-control studies**

- **Cohort studies**

Strength of Evidence

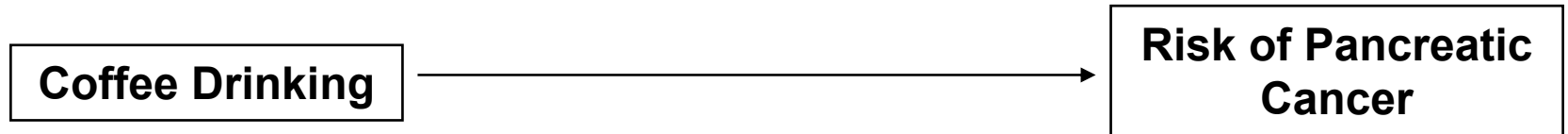


Relative Volume of Wind Turbine-Related Evidence by Type

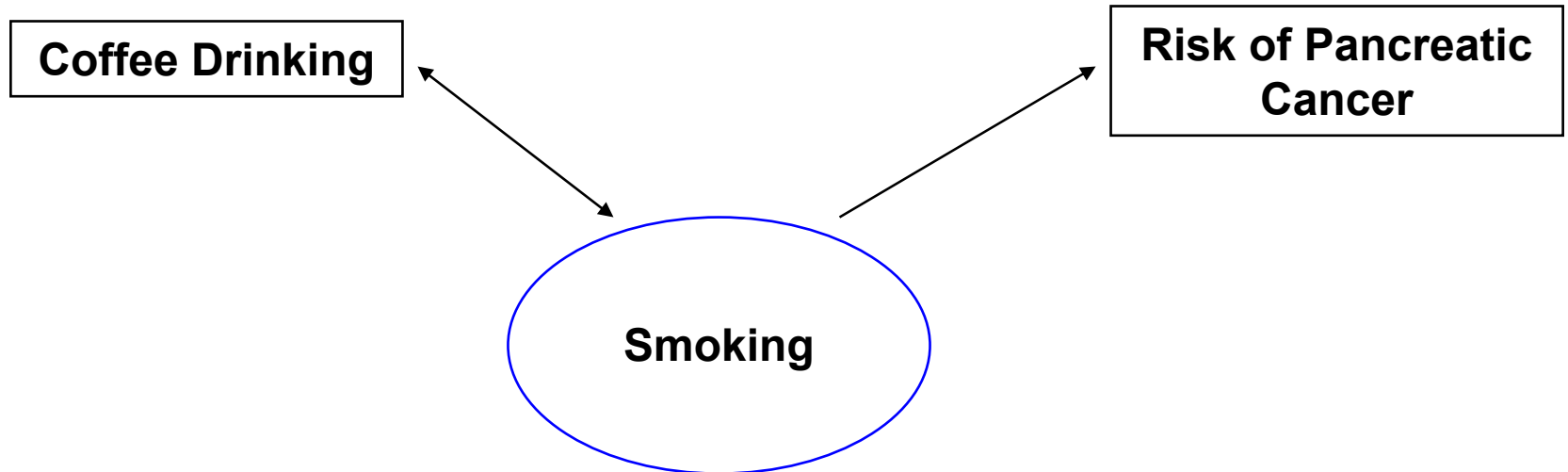
- | | |
|--|--|
| <input type="checkbox"/> No evidence of this type | <input checked="" type="checkbox"/> Moderate volume of evidence |
| <input checked="" type="checkbox"/> Minimal volume of evidence | <input checked="" type="checkbox"/> Substantial volume of evidence |

Confounding

Causal Association

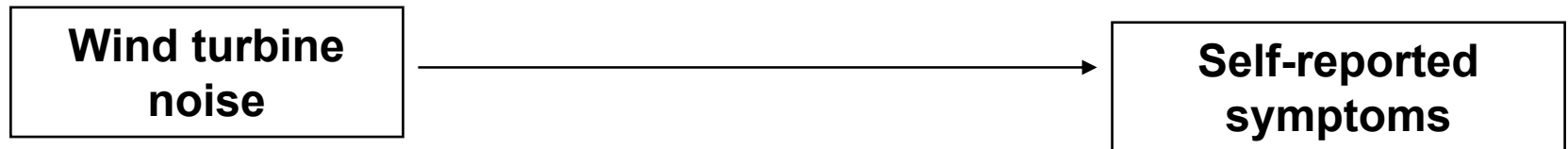


Due to Confounding

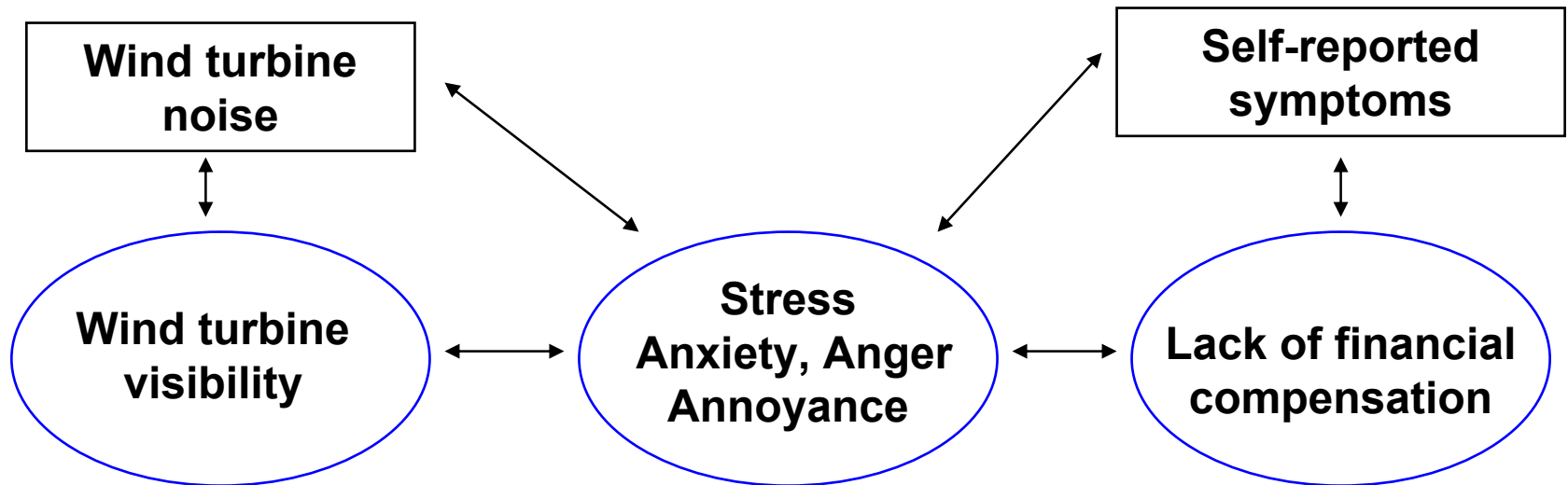


Confounding

Causal Association



Due to Confounding



Effect modifiers



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**
 - **There are few reports that have been written about wind turbines and health from an objective, dispassionate point of view**



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/Informal Surveys

- ☐ 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)
- ☐ All rely on self-reported outcomes



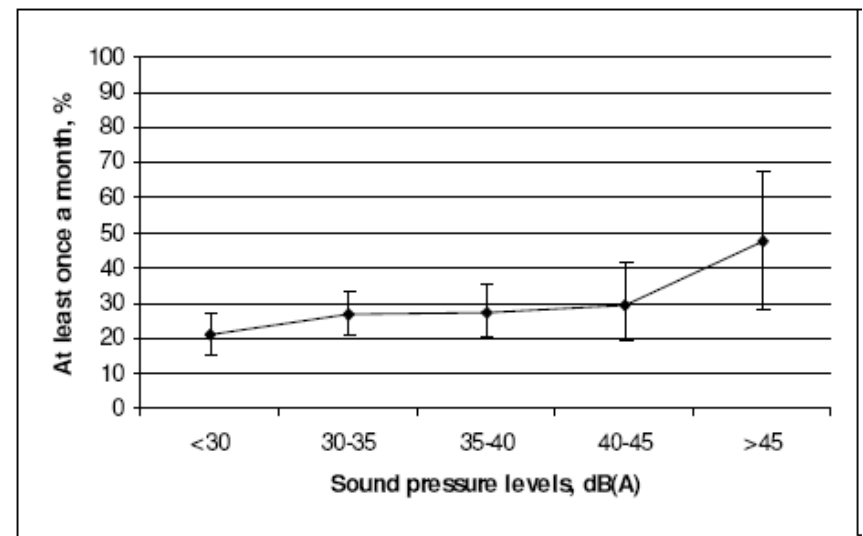
Studies of Wind Turbine Noise and Health

- **Case-control studies: none**
- **Cohort studies: none**

Project WINDFARMperception — Sleep

- 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 \geq once/month

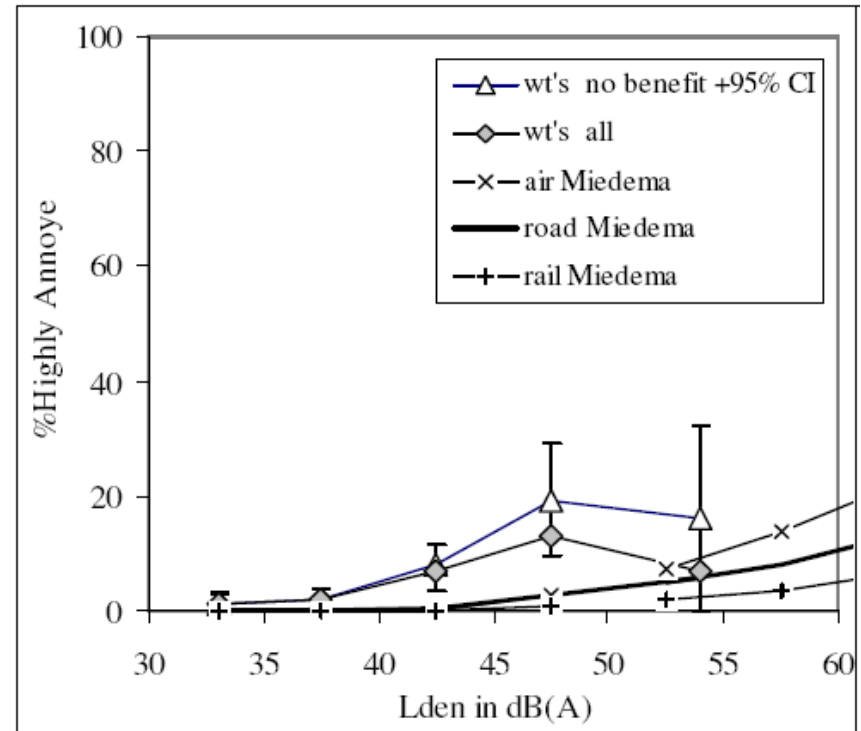
Relation between levels of wind turbine sound and self-reported sleep disturbance from wind turbines (only non participants included)



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



Project WINDFARMperception — 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.”

Pedersen, 2007

■ 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

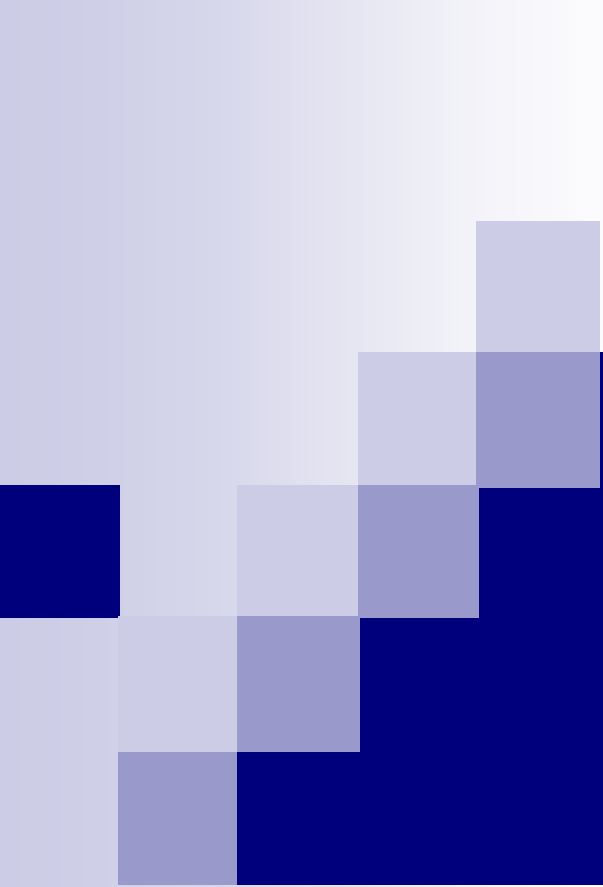
- ☐ Minimally assessed

■ 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**



World Health Organization Guidelines

WHO Night Noise Guidelines for Europe, 2009

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

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
Lnight,outside based primarily on findings of 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



**Where do we go
from here?**

Applicability of the Precautionary Principle

- **Definition:** When an activity raises threats of harm to human health or the environment, precautionary measures should be taken even if some cause and effect relationships are not fully established scientifically
- **Encourages increased transparency and public participation**
- **Depends in part on availability of alternative ways of achieving the same goal**
- **Consequences of inaction must be weighed against potential risks**
- **While a causal link is not necessary to invoke the precautionary principle, there must be some credible evidence of potentially significant impacts (a plausibility threshold)**
 - **A series of subjective reports do not provide compelling evidence of a potential public health threat**
- **Decisions on when to invoke the precautionary principle are the domain of policy makers as it involves weighing evidence of human health, environmental, and economic impacts**



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 for measurement of symptoms other than sleep disturbance
- 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
- Would only be able to assess association between proximity to wind turbines and risk of *reporting* adverse health effects
 - Would not allow for any conclusions regarding actual health outcomes



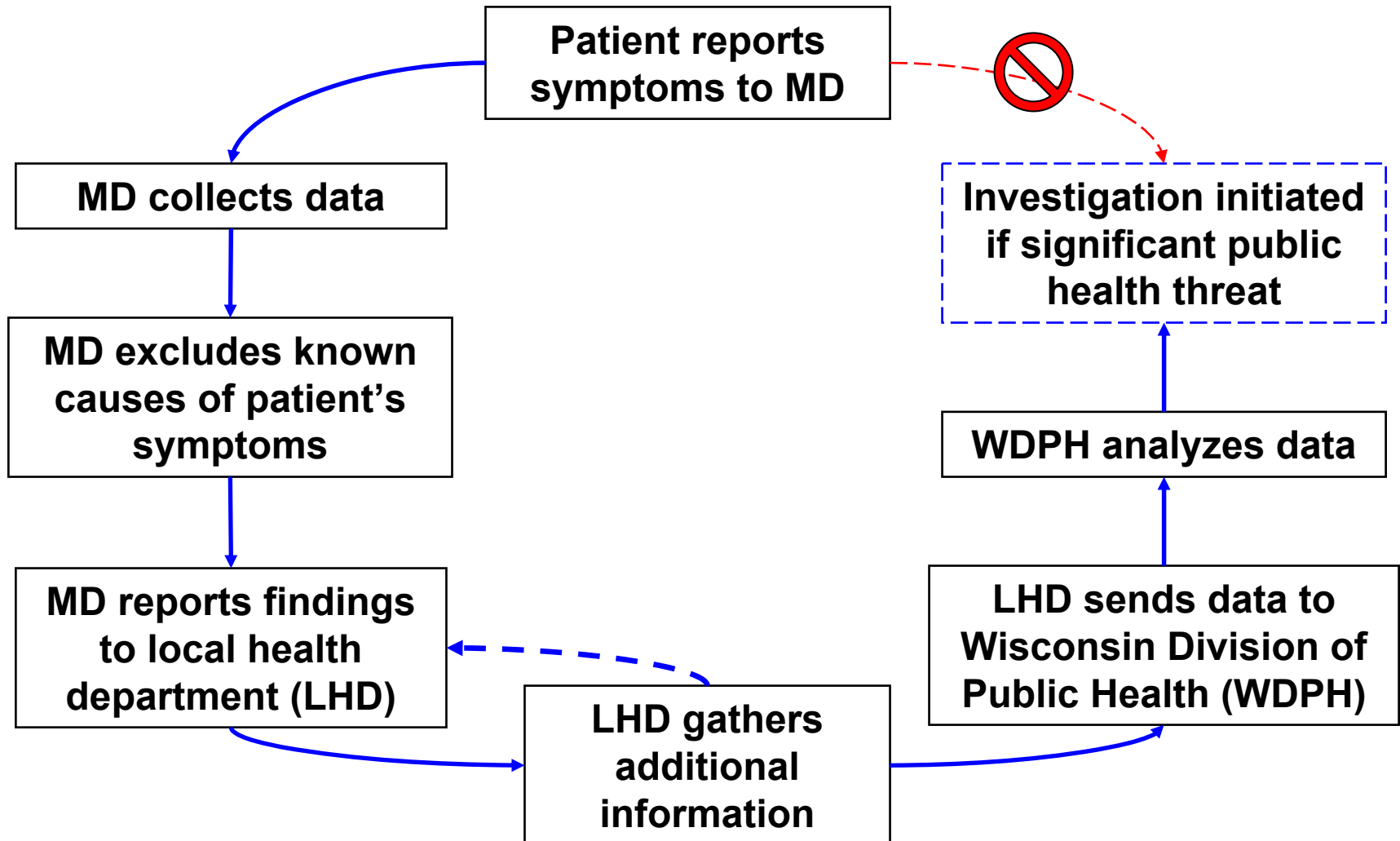
Sleep Disturbance — Hypothetical Study

- **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**

The Role of the Medical Community

- Assuming reported symptoms are solely related to an exogenous source (e.g. wind turbines) without evaluating for known causes of these symptoms is not consistent with best practices in medicine
- Persons with sleep problems that have led to compromised daytime functioning for more than a month should be medically evaluated
- Symptoms of sleep disturbance, vertigo, tinnitus, anxiety, etc. may represent serious underlying medical conditions that should be ruled out
- Healthcare providers have a critical role to play in assessing patient complaints
 - In this setting objective findings may be linked with subjective reports
 - Patient complaints assessed in the context of a medical history

Medicine & Public Health Coordination



General Conclusions

- Evidence does not support the conclusion that wind turbines *cause* or are *associated with* adverse health outcomes
- Gaps remain in our knowledge of the impact that wind energy may have on human health
 - Potential positive and potential negative impacts
- Passionate analyses, whether by proponents or opponents of wind energy development, may be subject to significant bias, which compromises credibility

General Conclusions

- **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**
- **Subjective reports of symptoms, in the absence of corresponding medical record data, do not provide compelling evidence of a significant public health threat**



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**
- **Recommend involving affected individuals in siting process**

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****Not all references included here are referenced in the presentation. This reference list also includes pertinent resources reviewed during the process of preparing this presentation.***

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