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
  - Wisconsin Department of Health Services, Division of Public Health, Bureau of Environmental and Occupational Health
  - University of Wisconsin, School of Medicine and Public Health
- **Related Outside Activities: None**
- **Conflicts of Interest: None**
- **Financial disclosures: None**

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

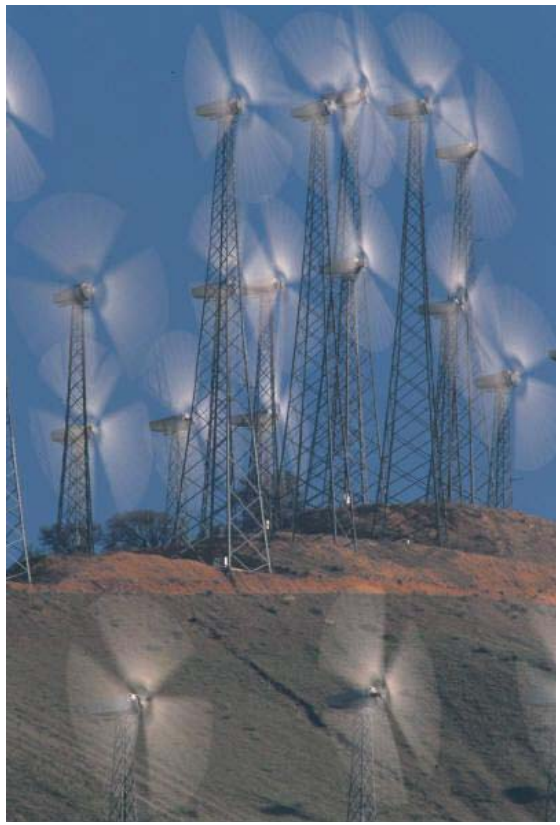
Potential Health & Safety Issues

- **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



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

NRC, 2007; National Epilepsy Foundation; Harding, 2008

Shadow Flicker

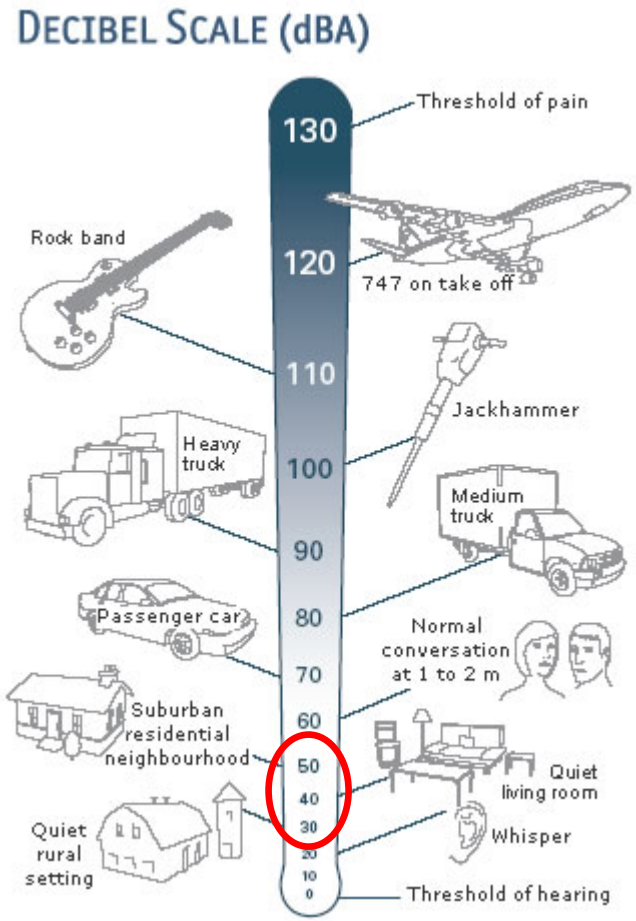
- Interruption of sunlight by helicopter blades has caused seizures
- 2 unconfirmed reports of seizures due to shadow flicker
- At ≤3 Hz risk is 1.7 per 100,000 photosensitive population (1.7 per 400 million persons)
- At typical wind turbine frequecies (0.6–1.0 Hz) shadow flicker is primarily an issue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

Passchier-Vermeer, 2000; Stansfeld, 2003; NIOSH, 1998, http://www.cdc.gov/niosh/docs/98-126/chap1.html

Observational Thresholds of Health Effects

Effect	Exposure type	Measure*	dB	Location of assessment
Hearing Impairment	Environmental	L_{aeq} (24 hr avg)	70	Indoors
	Occupational		75	
Hypertension	Environmental	L_{dn} (24 hr avg)	70	Outdoors
	Occupational	L_{aeq} (24 hr avg)	<85	Indoors
Ishchemic Heart Disease	Environmental	L_{aeq} (24 hr avg)	70	Outdoors
Annoyance	Environmental	L_{dn} (24 hr avg)	42#	Outdoors
	Occupational	L_{aeq} (24 hr avg)	Industry <85 Office <55	Indoors
Performance	School	L_{aeq} (avg during school day)	70	Outdoors
	Occupational		70	
Disturbance of Sleep pattern	Sleep	L_{aeq} (overnight avg)	<60	Outdoors
Awakening	Sleep	SEL	55	Indoors
Sleep Quality	Sleep	L_{aeq} (overnight avg)	40	Outdoors
Mood Next Day (sleep disturbance)	Sleep	L_{aeq} (overnight avg)	<60	Outdoors

§ The information contained in Table 1 was derived from Passchier-Vermeer and Passchier (2000).
* Noise levels presented in this table are presented as an equivalent sound level (L_{aeq}) 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.
# The dB level causing annoyance is approximately 12 dB lower for impulse noise.

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 turbulance**

Schust, 2004; Leventhall, 2004; NIEHS, 2001

Infrasound, LFN & Health

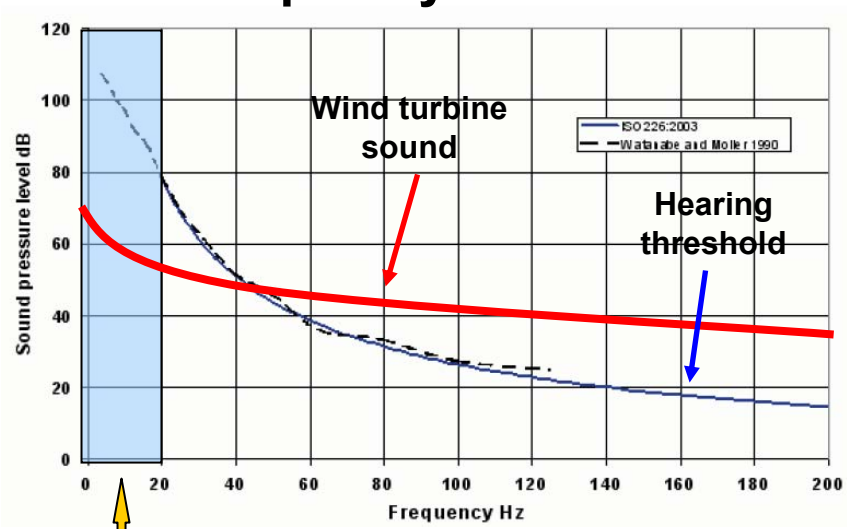
- **World Health Organization — *Guidelines for Community Noise, 2000***
  - **"The evidence on low-frequency noise is sufficiently strong to warrant immediate concern….Low-frequency noise may also produce vibrations and rattles as secondary effects. Health effects due to low-frequency components in 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



Infrasound

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

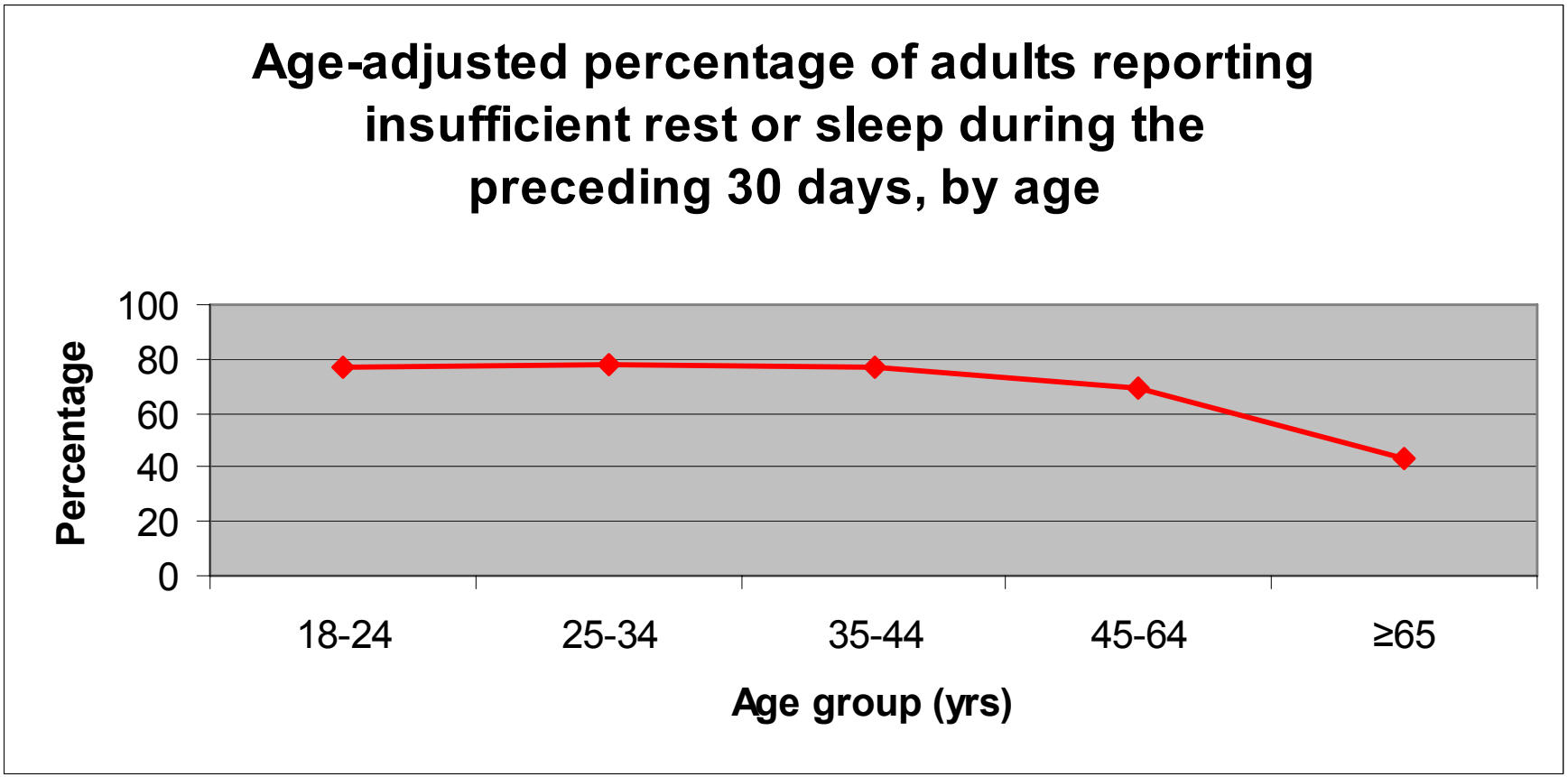
Michaud, 2007; Miedema, 2007

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

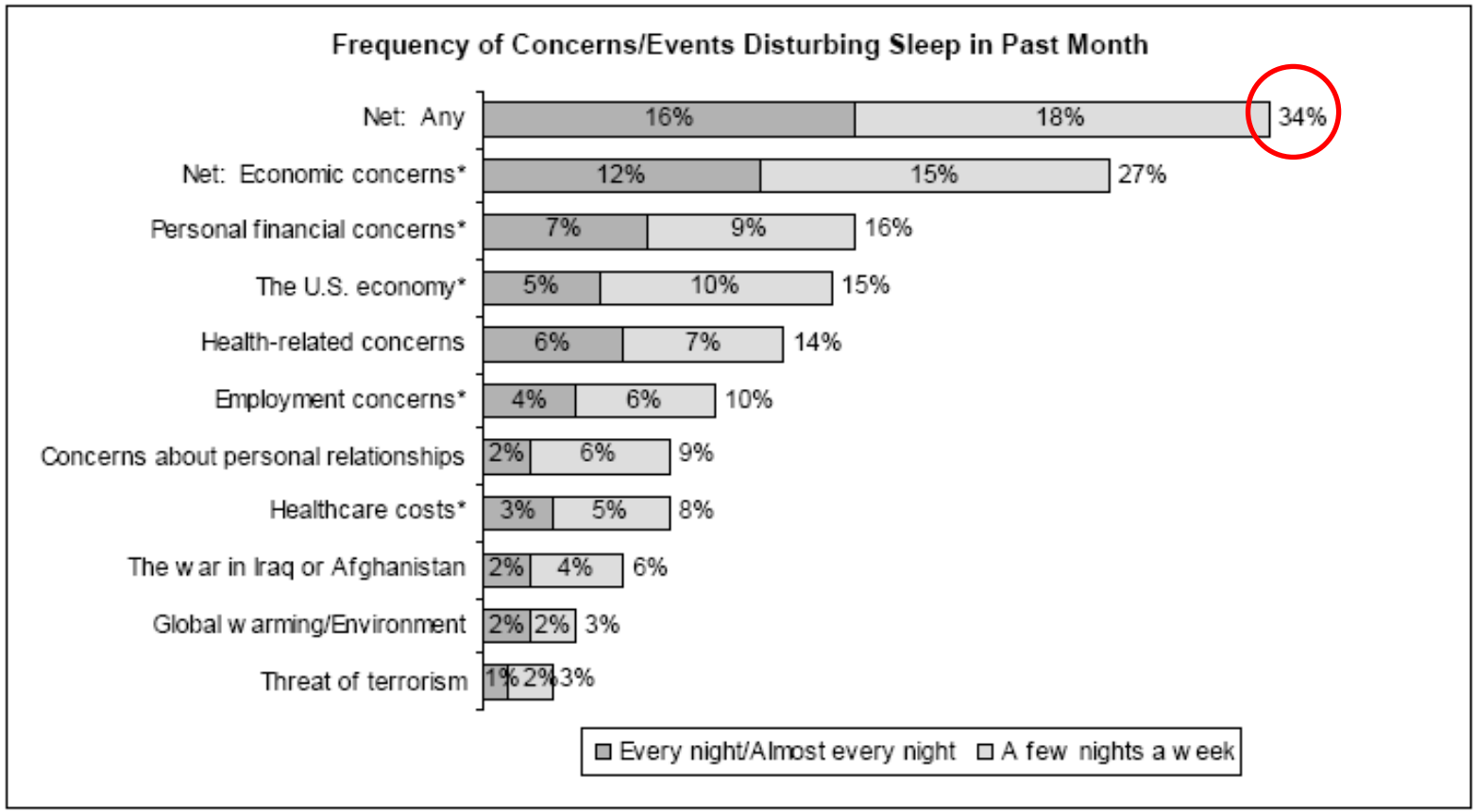
American Academy of Sleep Medicine, 2001; WHO Night Noise Guidelines

Sleep Insufficiency in the U.S.



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

Factors Affecting Sleep



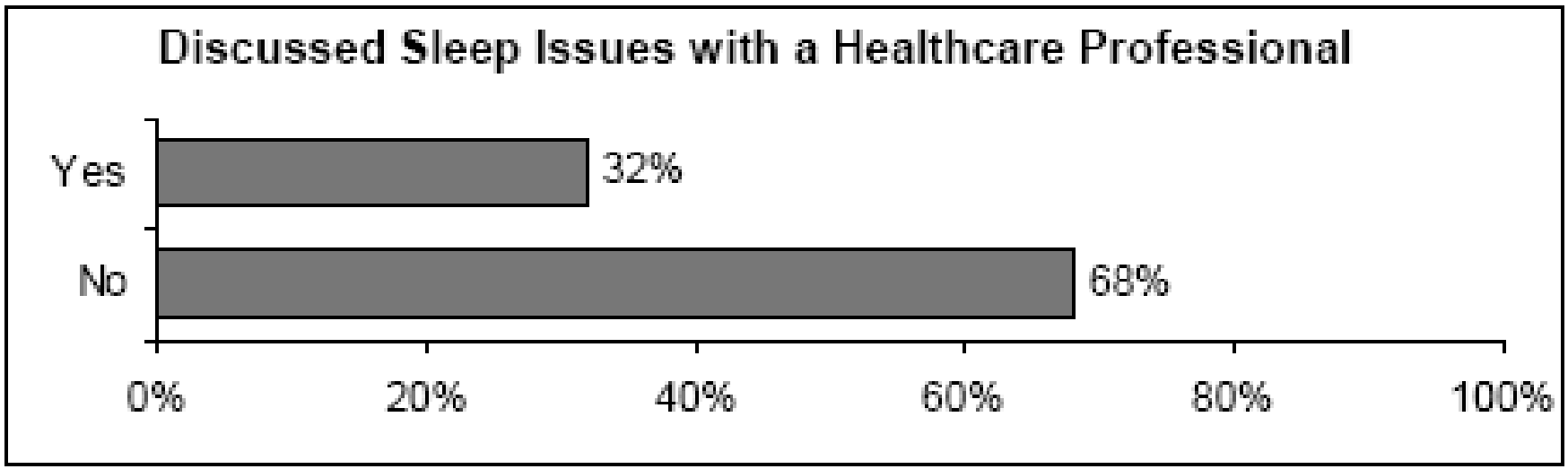
Base = Total sample (n=1,000)

*Note: This net includes the attributes of personal financial concerns, the U.S. economy, employment concerns and healthcare costs.

Q12

http://www.sleepfoundation.org/

Discussed Sleep Issues with a Healthcare Professional



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

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

Grimes. Lancet 2002;359:145-9

Descriptive Studies

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

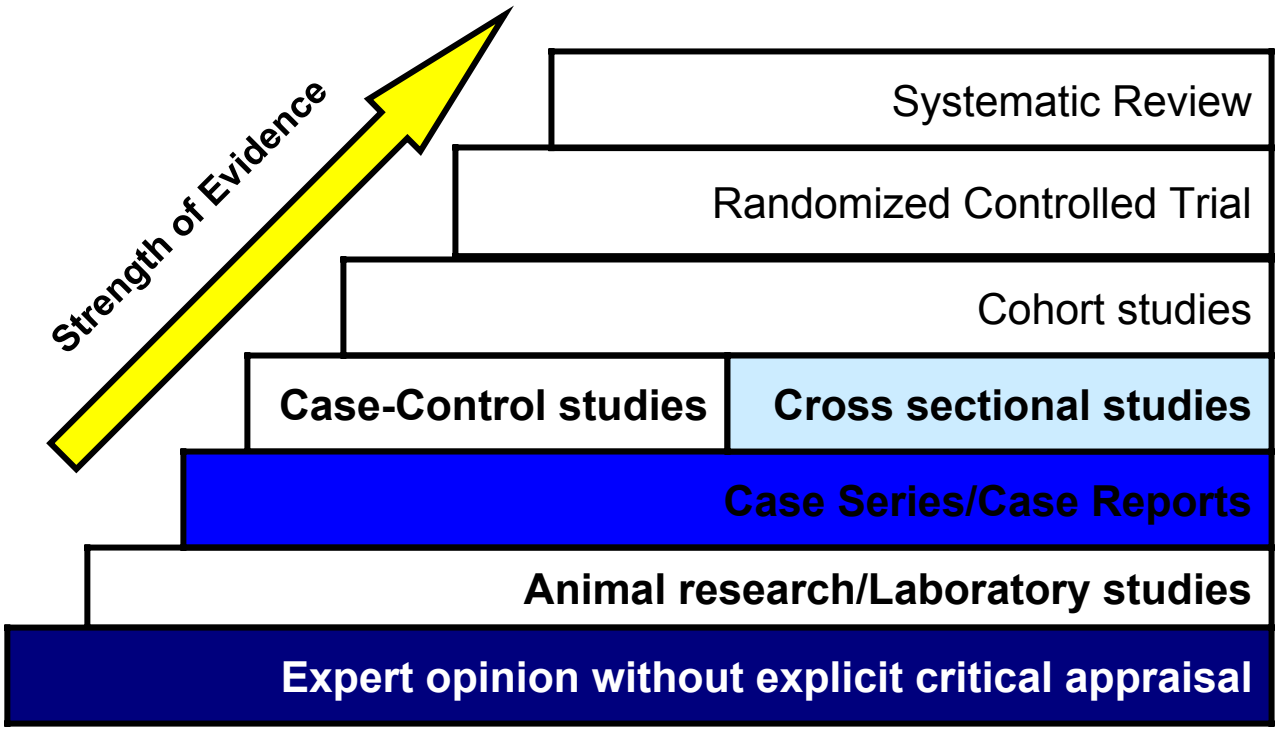
Grimes. Lancet 2002;359:145-9

Analytic Studies

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

Gordis. Epidemiology, 2nd ed. 2000.

Strength of Evidence



Outcomes

Strongest evidence of causal relationship

Strong evidence of causal relationship

Risk of disease association with exposure; temporality

Odds of case being exposed

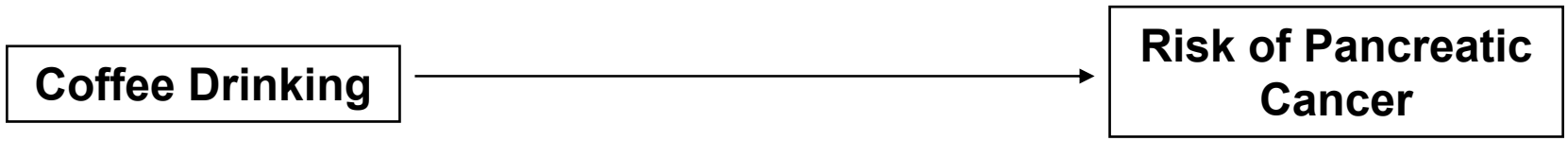
Hypothesis generation; Case definition formulation

Disease pathophysiology hypothesis generation

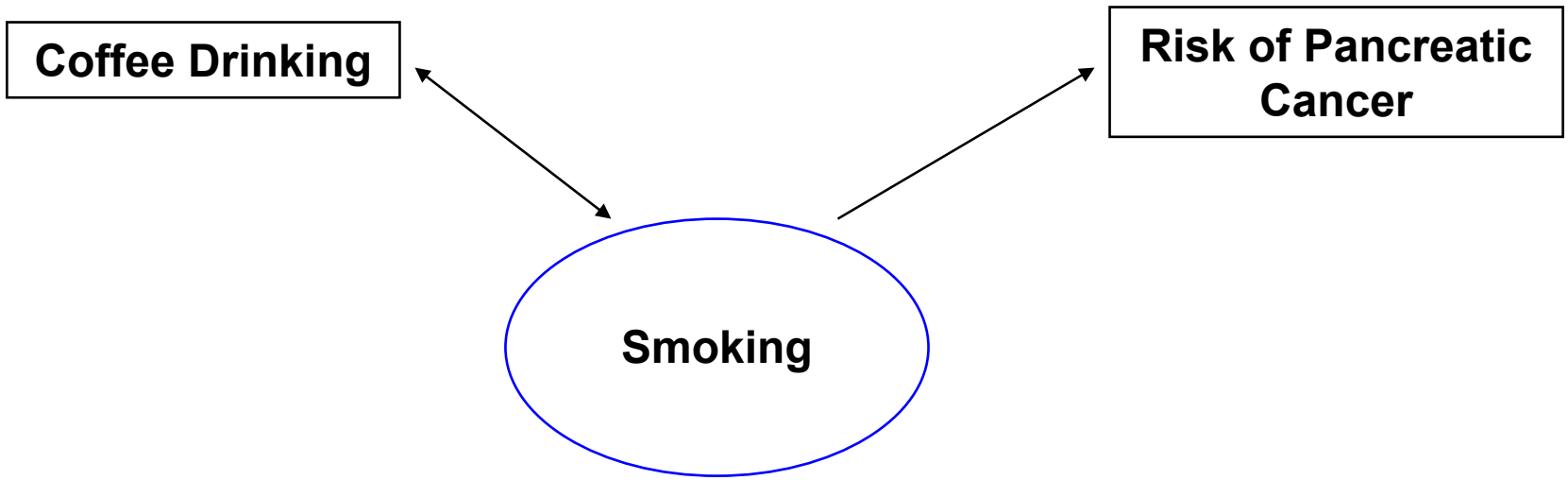
Adapted from Cebt.net, 2009; Zaccai, 2004; Gordis. Epidemiology, 2nd ed. 2000.

Confounding

Causal Association



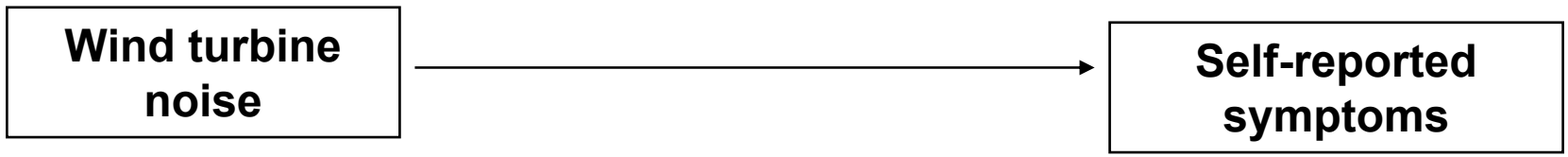
Due to Confounding



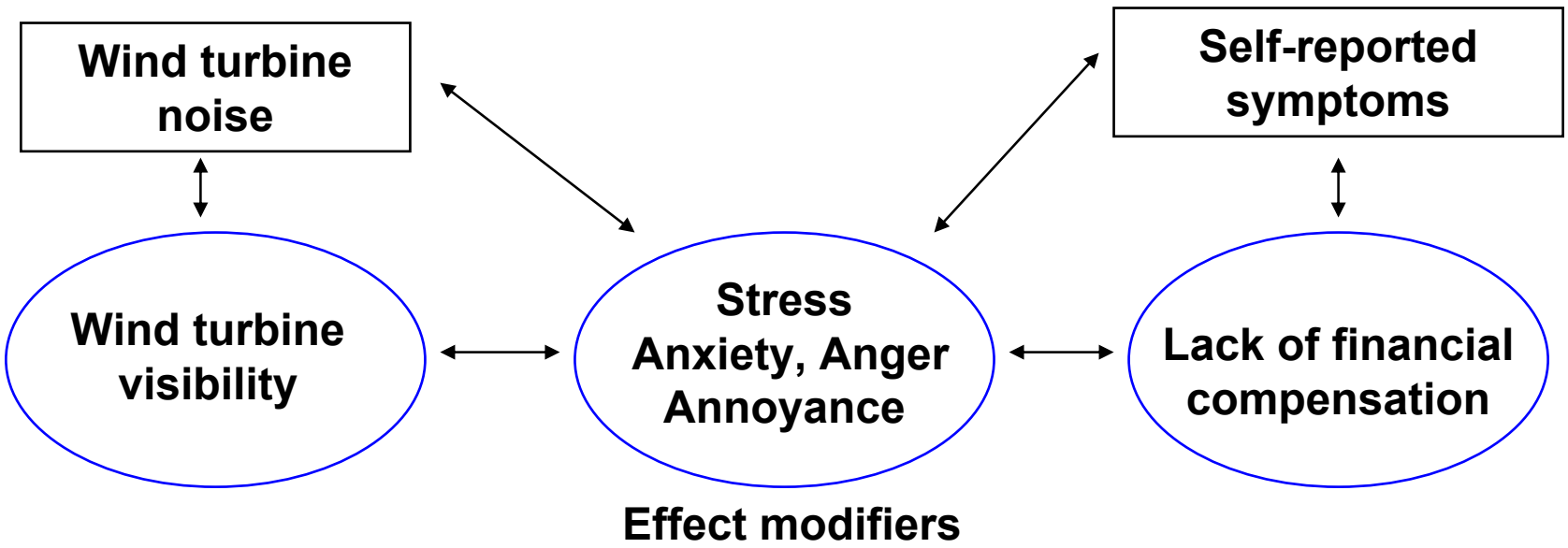
Gordis. Epidemiology, 2nd ed. 2000.

Confounding

Causal Association



Due to Confounding



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?

Zaccai JH. *Postgrad Med J*. 1004;80:140-147.
Greenhalgh T. *BMJ*. 1997;315:305-308.

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

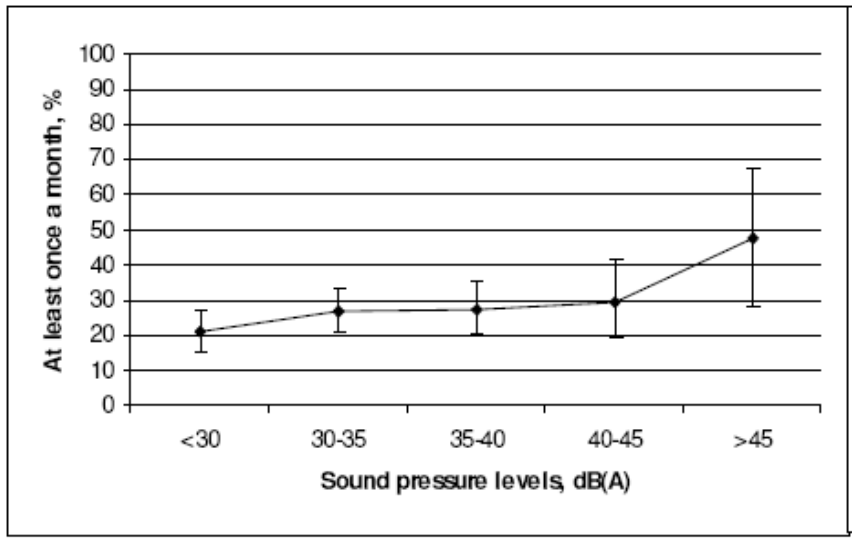
Studies of Wind Turbine Noise and Health

- 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

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 ≥once/month

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

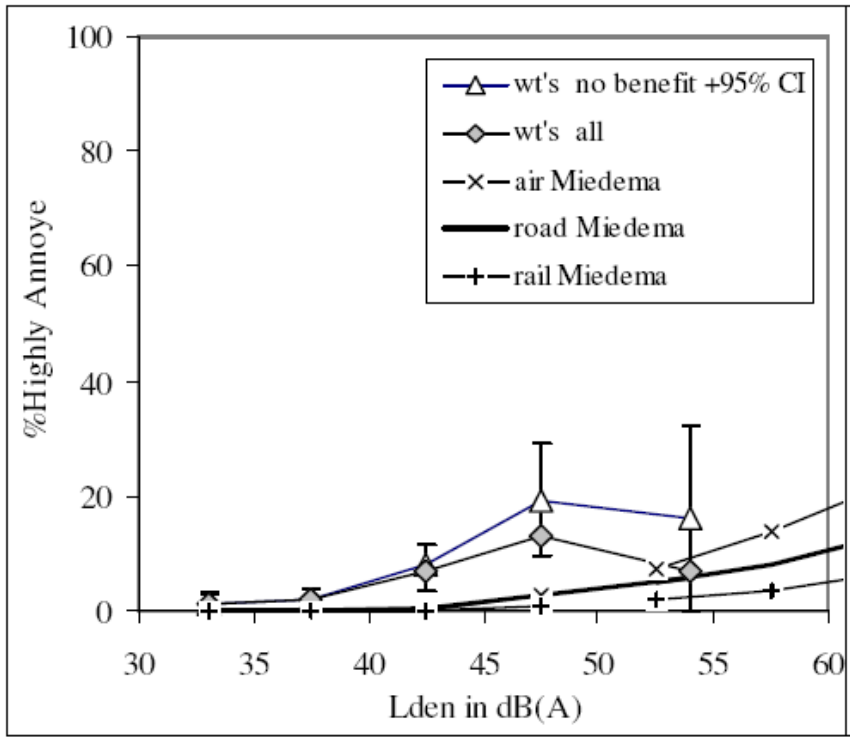


Van den Berg, 2008

Project WINDFARMperception — Annoyance

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

Relation between sound level Lden and percentage highly annoyed residents exposed to that sound, for three transportation noise sources and for wind turbines



Van den Berg, 2008

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."

Van den Berg, 2008

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 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

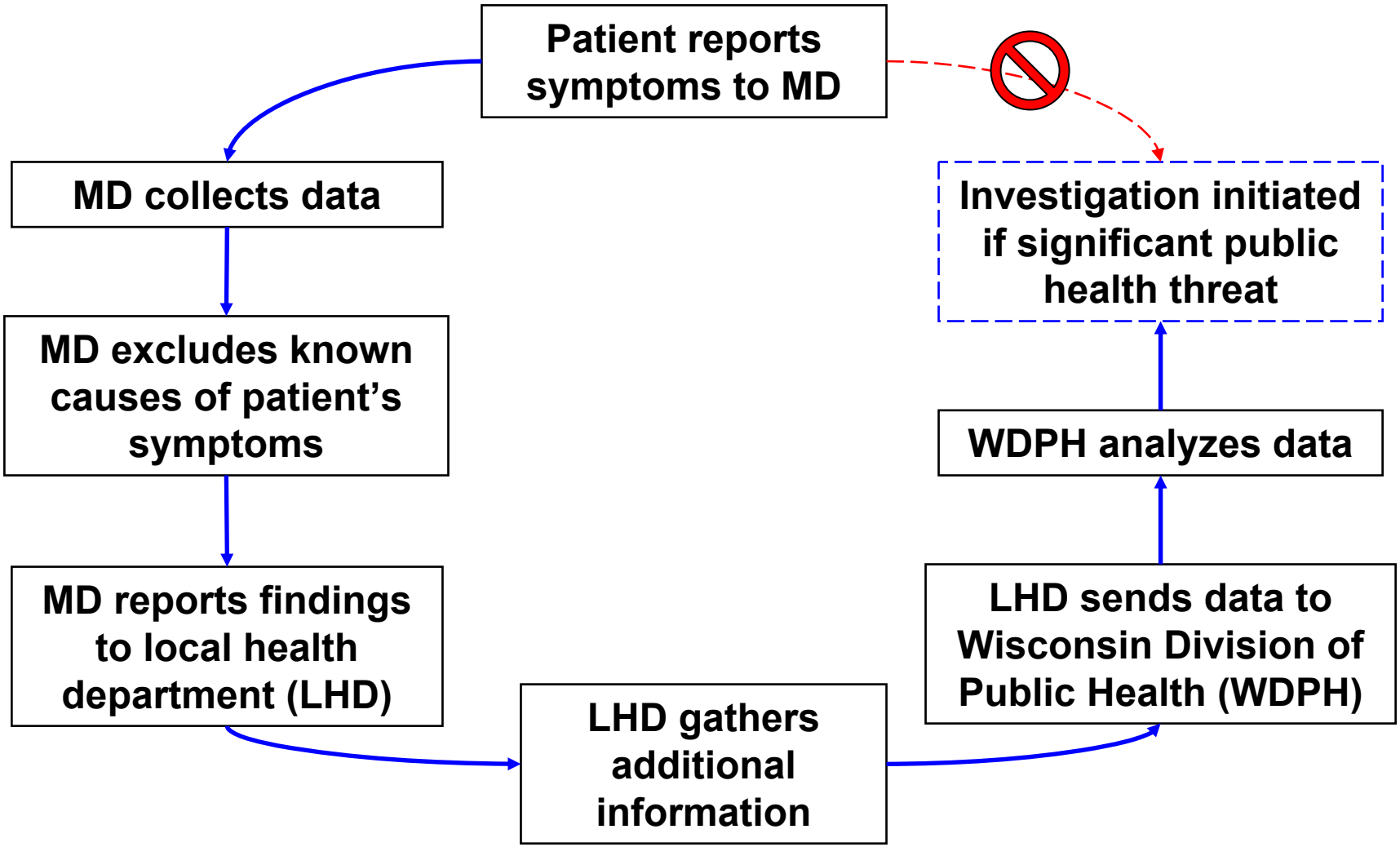
Sleep Disturbance — Hypothetical Study

- 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

Medicine & Public Health Coordination



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