Can the Sound Generated by Modern Wind Turbines Affect the Health of Those Living Nearby?

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Windmills have always been Industrial Machines.

Some are beautiful and remind us of days gone by.
Modern wind farms are equally industrial but not so quaint (unless there happens to be a castle nearby).
Wind turbines have been getting bigger and bigger....

Lars Ceranna, Gernot Hartmann, and Manfred Henger.
Infrasound Workshop 2005, Tahiti

Rotor diameter (126m = 413ft) is bigger than a football field including both end zones!

The world's largest wind turbine is now the Enron E-106. This turbine has a rotor diameter of 126 meters (413 feet). The E-106 is a more sophisticated version of the E-99, formerly the world's largest wind turbine and rated at 6 megawatts. This new
Wind turbines are “green” and are contributing to our energy needs.
The goal is to generate 20% of the electricity for the USA with wind turbines.

By 2030, the plan is to install 300 GW.

That is 300,000 MW which is approximately 150,000 2 MW turbines.

We are currently around here with 40 GW capacity.
And they may be coming to locations near you!

So far, this is all good news.

Data Source: AWS Truewind, LLC, for windNavigator® for the National Renewable Energy Laboratory

++ + Ontario, Canada
A potential problem

They are installing these machines as little as 300m from people’s homes
Is the sound from wind turbines a problem?

British Wind Energy Association: Wind farm at 350m
35-45 dBA

“...the sound of a wind turbine generating electricity is likely to be about the same level as noise from a flowing stream about 50-100 meters away or the noise of leaves rustling in a gentle breeze. This is similar to the sound level inside a typical living room with a gas fire switched on, or the reading room of a library or in an unoccupied, quiet, air-conditioned office.”

American Wind Energy Association – Tom Gray
“Wind turbine noise (at 200 m) is as loud as your refrigerator heard from the living room”.

Washington University Brown Bag Seminar, May 2011
Then why is Annoyance so high?

There’s something about wind turbine noise people don’t like!
Sound from Windmills: Wind Turbine Syndrome

Clinical symptoms first formally identified by British physician Amanda Harry, MD.

- sleep disturbance 89%
- headache 56%
- tinnitus 58%
- ear pressure / pain 30%
- dizziness / vertigo 59%
- nausea
- visual blurring
- tachycardia (rapid heart rate) 76%
- irritability
- problems with concentration and memory 93%
- panic episodes

%ages above from Pierpont
N=21 to 38 people surveyed expressing problems

Dr. Nina Pierpont, MD, 2009
(self-published book)
Epidemiology

- Harry 2007: 39 people living 300m-2 km from turbines. 81% believed their health was adversely affected.
- Pierpont 2009: 40 people self-reported as having problems.
- Nissenbaum (2010): 22 adults within 3500’ compared with 27 “matched” people living about 3 miles away. Surveys of symptoms (similar to prior studies), validated surveys of sleep status and quality of life. (presently in peer review). Reports a strong correlation between sleep status and distance from the turbines even in the control group!!!
- Laurie (2010): Longitudinal monitoring of morning blood pressure. Found elevation on days the turbines were running.

Each has been an unfunded, volunteer study by private individual. As a result they have largely been dismissed by the wind turbine industry.

- No study yet relating symptoms to turbine noise characteristics/level.
Other reasons the problem may be real

• Many individuals now reporting symptoms were initially turbine supporters, and changed when the turbines started up. They feel they were misled by claims the turbines were quiet.

• Some people buy/rent second homes to sleep in, or abandon their homes because they cannot stand to sleep there. This is often at great financial hardship as it is difficult to sell the home near the turbine. People would not do this just to make a political point.
Health Issues / Disease / Pathology

- Not everyone affected.
- Not all turbines cause problems.
- For those affected, symptoms go away when not near turbine.
- No expected pathology / damage.

- In terms of health, somewhat analogous to motion sickness. Not a disease, but still very unpleasant when it affects you.
Noise /Health Issues from the Industry Perspective

• There are no health effects of wind turbines
• People who complain are NIMBYs
• Some may find the noise annoying. Annoyance is not a health issue. Sick and annoyed are not the same thing (Colby).
• Nocebo effect (bad attitude to turbines).
• No noise monitoring is necessary.
• No further scientific studies are necessary

Colby CANWEA 2009. “Panel members agree that the number and uncontrolled nature of existing case reports of adverse health effects alleged to be associated with wind turbines are insufficient to advocate for funding further studies.”

Dobie 2011 interview “I would not like to see my tax dollars spent on this when there are much more important issues in medical research.”
Current Litigation / Hearings

• Australian Senate Commission – Hearings into the social and economic impacts of wind farms.
• Ontario, Canada. Kent Breeze environmental tribunal.
• plus many more contentious “local” planning meetings.
• Problem turbines: Falmouth, Mars Hill, Vinalhaven (USA), Toora, Waubra (Australia), Wolfe Island (Canada)
Sound Characteristics: Wind Turbine Spectra

Bo Sondergaard (2008)
Delta Report “Low Frequency Noise from Large Wind Turbines”

Peak energy at around 500 Hz

The spectra are interested in the sound you can hear – these spectra have been “A-weighted” i.e. weighted according to human hearing sensitivity.
Kampermann: Re-analysis of Bo Søndergaard’s measurements to remove A-weighting

Sound Power spectra of wind turbines
Normalized to 1 MW output at 8m/s (10m)
From DELTA Danish Electronics: WT Noise 2007
Wind Turbine noise shown as unweighted spectra

Van den Berg, 2004

Spectrogram down to 10 Hz

Modern 1.5 MW GE turbine at 1500 feet

90dB and greater peaks at 20 Hz

Pulsatile blade swish at 40-50 dB at ~500 HZ

Harmonics of blade-passing frequency

Under some conditions, sound levels are over 90 dB SPL below 20 Hz.

Refrigerators do not generate infrasound to this degree!

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Infrasound generation depends in “input turbulence”

- No obstructions, etc
- Calm evening
- Ridgelines
- Multiple Turbines Close Together

Infrasound low
Infrasound higher
Infrasound higher
Infrasound higher

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Wind turbine infrasound is at levels that cannot be heard

![Wind Turbine Noise Spectra](chart.png)

Van den Berg 2006
Jung and Cheung 2008
Human Hearing

Washington University
The Wind Industry Position

“Renewable UK”, the website of the British Wind Energy Association use this quotation from Dr. Leventhall, one of their consultants.

“I can state quite categorically that there is no significant infrasound from current designs of wind turbines”

The critical word above is “significant”. If you cannot hear the sound it is assumed to be insignificant.

8. Unusual perception

The evidence is that the ear is the most sensitive receptor for infrasound and low-frequency sound, that if you cannot hear a sound you cannot perceive it in other ways and it does not affect you. However, unusual sensitivity is sometimes reported, for example by Feldmann and Piten (2004). Here a family complained of disturbance at night, and consequent effects on health, allegedly caused by noise from a boiler house.

If you can’t hear a sound…it does not affect you
Hearing in guinea pigs compared to humans

Low frequency hearing sensitivity correlates well with cochlear length

The guinea pig cochlea is about half the length of the human

Guinea pigs are about 10-20 dB LESS sensitive than humans

West, JASA 1985
Our Experience with Guinea Pigs and Infrasound

Is the ear insensitive to infrasound?

Salt & DeMott, JASA 1999

*Stimulus:* Fluid pressure delivered from a pipette sealed into scala vestibuli.

*Measuring potential from endolymphatic compartment of second cochlear turn.*

Absolutely HUGE cochlear microphonics! 24 mV pk/pk (EP was 72 mV) (but this was not airborne sound)
Cochlear Microphonic Biasing Experiments

Looking at low frequency bias effects on transduction.

Because we wanted multiple “windows” we used a very low frequency bias: 4.8 Hz.
Bias tones are effective down to 80 dB SPL at 4.8 Hz!

30 – 40 dB below presumed hearing threshold.
Electrical recording from the guinea pig ear (cochlear microphonics)

**Guinea Pig Hearing**

- **Human Hearing**
- **Guinea Pig Hearing**
- **GP Microphonics**

**Cochlear Microphonic Response Amplitudes**

- **500 Hz**
- **50 Hz**
- **5 Hz**
- **Noise Floor**

Recording from scala media of the third turn of guinea pig (with averaging and band-pass filtering).
Explanation – Two types of sensory cell in the Ear

Two types of Hair Cells in the Cochlea

Inner Hair Cells (IHC)
- Responsible for HEARING
- Hairs do NOT contact Tect. Memb.
- *Respond to VELOCITY
  (velocity decreases 6 dB/oct as frequency is lowered)
  * Based on Cheatham and Dallos, 2001

Outer Hair Cells (OHC)
- Generate Cochlear Microphonics
- Hairs Contact Tect. Memb.
- *Respond to DISPLACEMENT
  (displacement constant with frequency for fixed input level)

Image Courtesy of Saumil Merchant MD, Mass Eye and Ear Infirmary, Harvard Medical School
IHC and OHC respond differently as sound frequency is changed.

- IHC respond to velocity
- OHC respond to displacement

\[ \text{Displacement} \]

\[ \text{Time} \]

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We hear through our INNER HAIR CELLS. As they are insensitive to infrasound, we don’t hear the infrasound.

OUTER HAIR CELLS generate the cochlear microphonic response. They are stimulated at ~40 dB lower sound levels at low frequencies.
Wind Turbine Sounds you don’t Hear will stimulate the OHC

Sound in the gray, shaded area (5 – 50 Hz) will not be heard but will stimulate the OHC
Connections within the brain

Hearing

Infrasound

Self Cancellation circuit

From Kaltenbach and Godfrey, 2006
Important
Conclusions

• Outer Hair Cells detect and transduce low frequency sounds at levels substantially below those that are heard.

• OHC stimulation by unheard low frequency sound could cause sensations of fullness, pressure or tinnitus and may disturb sleep.

• “What you can’t hear can’t affect you” is FALSE
Helicotrema effects

Helicotrema in HUMAN is expected to attenuate frequencies below 100 Hz by 6 dB/octave

Plugging helicotrema in guinea pigs increases sensitivity below 100 Hz by about 6 dB/octave
Amplitude Modulation

- Blade “swish” and blade “thump” are perceived as a highly annoying character of wind turbine noise
- Swish: audible downstroke of blade, disappears with distance downwind, and at hub height (Bowdler 2010).
- Thump: Asymmetric waveform, more apparent with turbulent wind, more apparent downwind (Bowdler 2010).
Measures of Amplitude Modulation (Blade Swish)

High Pass Filtered at 20 Hz – Audible Sound without Infrasound

Audible sound measured with the sound level meter (A-weighted, so no infrasound) varies up and down with time.

The envelope represents an infrasonic frequency.

It has been assumed that this represents the modulation that annoys people.
Waveform changes (altered amplitude and distortions) of the cochlear microphonic as low frequency bias tones drive the “operating point” up and down the cochlear transducer curve.
Amplitude modulation of single unit responses

Auditory nerve fiber responses from cat collected by Jeff Lichtenhan, Harvard Medical School

Unresponsive with no stimulus

910 Hz probe stimulates the fiber
Amplitude modulation of single unit responses

Auditory nerve fiber responses from cat collected by Jeff Lichtenhan, Harvard Medical School

Single-Fiber Histograms

Alone, the 50 Hz tone doesn’t affect the fiber at any level
Amplitude modulation of single unit responses

Auditory nerve fiber responses from cat collected by Jeff Lichtenhan, Harvard Medical School

When combined, the 50 Hz tone amplitude modulates the 910 Hz responses

This form of amplitude modulation by sub-audible low frequency sounds is biological in origins and cannot be measured with a sound level meter.
Amplitude modulation of single unit responses

Auditory nerve fiber responses from cat collected by Jeff Lichtenhan, Harvard Medical School

This result requires the IHC to be less sensitive to the 50 Hz tone while the OHC detect the 50 Hz at these levels and respond by changing their amplification at 910 Hz.

These data provide further confirmation that IHC and OHC have different response characteristics, with the OHC more sensitive to low frequency stimuli.
Conclusions – Amplitude Modulation

• Modulated sound levels, such as blade swish and blade thump can be measured by a sound level meter.

• In addition, there can be a BIOLOGICAL modulation of audible (higher frequency) sounds by infrasound. This is caused by the OHC gain and response characteristics changing as the operating point of the outer hair cells is displaced by the infrasound.

Note: There are many publications (> 50) related to operating point and cochlear responses. This is not a new concept.
Considerations of infrasound exposure in the home.

Exposure duration may be considerably longer than the work week. Includes weekends, morning, evening, nighttime. Exposure may be 24 hrs a day, 7 days a week if the person doesn’t work.

Infrasound travels further (is attenuated less with distance) than higher frequency sounds which are attenuated by vegetation, etc.

Infrasound is not attenuated by the house structure, even though audible sounds are attenuated.

The maximum influence of infrasound probably occurs while in a quiet room (e.g. sleeping in a bedroom).
A-weighting noise measurements

Not a “minor correction”!

Over 140 dB at 1 Hz.

Is only valid if “hearing” is the important issue.

If other structures of the ear respond at levels lower than the heard level, A-weighting is inappropriate.

Rustling of Leaves 😊
Analogy with UV light filtering

Ultraviolet (UV) light is invisible...

...but it can affect you.

Photokeratitis, “snow blindness”
“welder’s flash”
+ cataracts

Sunburn
“A-weighting” principle applied to UV light

Adjust sunlight spectrum to only show what is VISIBLE

Conclude that there is nothing that can harm you.
You don’t need sunscreen.
You don’t need sunglasses.
Go spend all day laying out in the sun. 😊

This approach isn’t rational when applied to light,
So how can similar logic applied to sound???

Measuring visible light (e.g. taking photographs with a regular camera) tells you nothing about UV content.
A-weighted measurements tell you nothing about the infrasound content.
Show Me the Noise!

- Most video recorders (e.g. news crews), home camcorders, tape recorders, cellphones, etc. are incapable of detecting wind turbine infrasound.
- Most speakers will not generate sounds below 20 Hz.
- YouTube videos showing how quiet or noisy wind turbines are are meaningless.
- Radio shows cannot demonstrate what it sounds like.
- This makes it difficult to show people such as politicians and wind turbine executives what the problem is. Many people do not really understand what infrasound is. It requires a technical background to understand.
Conclusions with regard to wind turbines

- The ear is sensitive to low frequency sounds at the levels generated by some wind turbines.
- People disturbed by wind turbines placed near their homes don’t think they are being treated fairly.
- There is considerable resistance from the wind turbine companies to accept that a problem could exist.
- There is a lack of understanding of wind turbine noise character, how best to measure it, and how it influences the ear.
- More auditory physiologists need to become active in this area. Our field has let down both the engineering community and the public by not presenting what is known about the ear in a form that those outside the auditory neuroscience community can understand.
What should be done?

- Increase the “setback” distance to one where fewer people experience symptoms, e.g. 2 km, until the issue is better understood.
- Noise monitoring (not A-weighted, but including infrasound) in homes closer than the 2 km setback distance.
- Fund longitudinal epidemiological studies (blood pressure, sleep status, etc) in conjunction with noise measurements (blind to subjects) to assess whether symptoms correlate with turbine noise and/or infrasound.
- Long term audiology monitoring of those living nearby (possible accelerated presbyacusis).
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