Does the infrasound from wind turbines affect the inner ear?

Alec N. Salt, Ph.D.

Department of Otolaryngology, Washington University School of Medicine, St. Louis, USA,

ABSTRACT

There is controversy whether prolonged exposure to the sounds generated by wind turbines adversely affects human health. The unweighted spectrum of wind turbine noise slowly rises with decreasing frequency, with greatest output in the 1-2 Hz range. As human hearing is insensitive to infrasound (needing over 120 dB SPL to detect 2 Hz) it is claimed that infrasound generated by wind turbines is below threshold and therefore cannot affect people. The inner hair cells (IHC) of the cochlea, through which hearing is mediated, are velocity-sensitive and insensitive to low frequency sounds. The outer hair cells (OHC), in contrast, are displacement-sensitive and respond to infrasonic frequencies at levels up to 40 dB below those that are heard. A review found the G-weighted noise levels generated by wind turbines with upwind rotors to be approximately 70 dB G . This is substantially below the threshold for hearing infrasound which is 95 dB G but is above the calculated level for OHC stimulation of 60 dB G. This suggests that most wind turbines will be producing an unheard stimulation of OHC. Whether this is conveyed to the brain by type II afferent fibers or influences other aspects of sound perception is not known. Listeners find the so-called amplitude modulation of higher frequency sounds (described as blade "swish" or "thump") highly annoying. This could represent either a modulation of audible sounds (as detected by a sound level meter) or a biological modulation caused by variation of OHC gain as operating point is biased by the infrasound. Cochlear responses to infrasound also depend on audible input, with audible tones suppressing cochlear microphonic responses to infrasound in animals. These findings demonstrate that the response of the inner ear to infrasound is complex and needs to be understood in more detail before it can be concluded that the ear cannot be affected by wind turbine noise.

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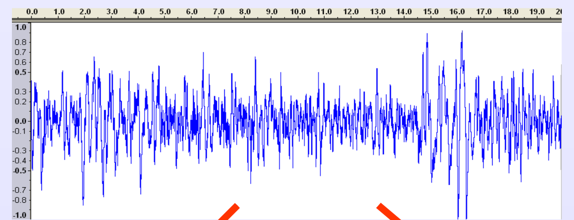
Wind Turbine Sounds Contain High Levels of Infrasound

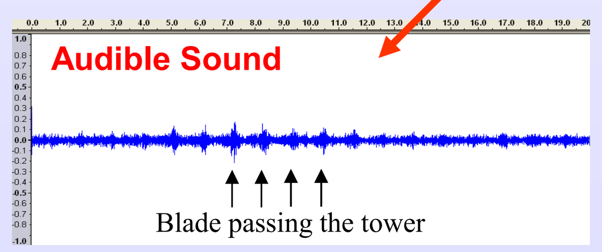
Original Recording



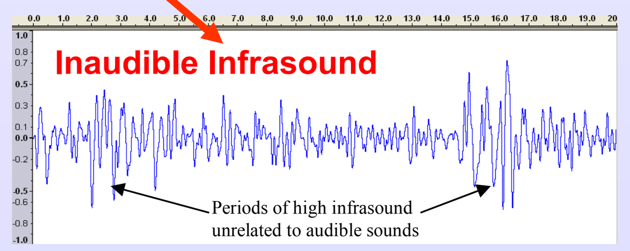
20 s recording in a home with a wind turbine located 1500' downwind

(recording courtesy of Rick James)

High-pass filtered at 20 Hz



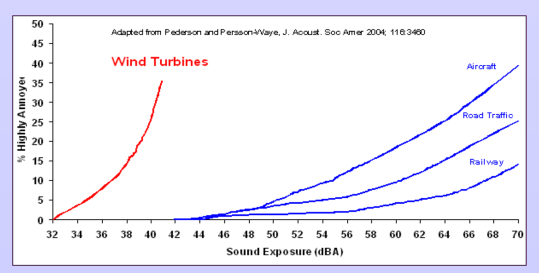
Low-pass filtered at 20 Hz



Wind Turbines are Erected near People's Homes

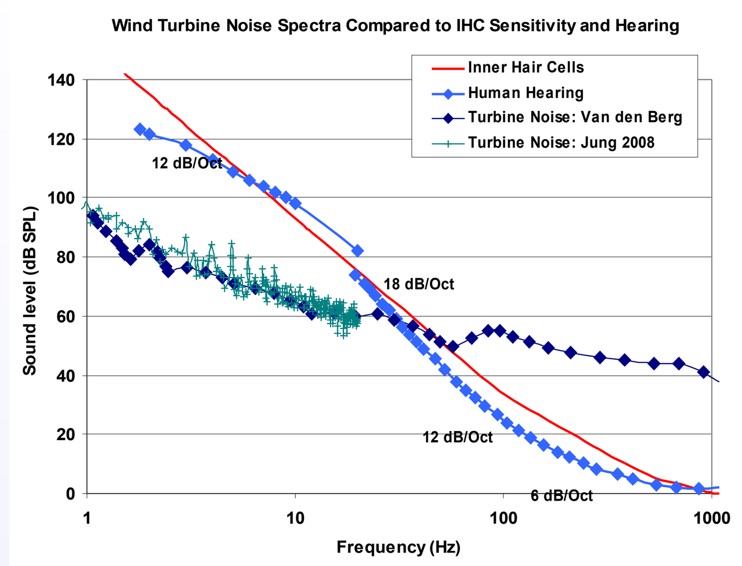
Many people find wind turbine noise disturbs their sleep, causes tinnitus, fullness and dizziness and elevates morning blood pressure. Some individuals cannot bear the noise and are disturbed enough to abandon their homes.

Wind Turbine Noise is Annoying at Low Levels



People find wind turbine noise substantially more annoying than most other types of noise. While other types of noise need to be > 70 dB A to annoy 30% of the subjects, wind turbine noise at approximately 40 dB A annoys 30% of the subjects.

Wind Turbine Infrasound is not Audible



This figure shows the sensitivity of human hearing (pale blue symbols) compared with the spectra of wind turbine sounds reported in two studies. Human hearing above 20 Hz is based on ISO226:2003 and hearing sensitivity to infrasounds from Møller and Pederson, 2004. Wind turbine sounds at infrasonic frequencies (< 20 Hz) are below the threshold of human hearing.

Widely Cited (but incorrect) Interpretations

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 Pitten (2004). Here a family complained of disturbance at night, and consequent effects on health, allegedly caused by noise from a boiler house.

Leventhall G. What is infrasound?Progress in Biophysics and Molecular Biology 2007; 93: 130–137

The blade passing the tower has been mentioned as a specific source of low frequency noise. A theoretical study of this phenomenon has been conducted by RISØ DTU. The result is that this blade/tower interaction generates noise only at the lowest frequencies with a decreasing level with increasing frequency. The study confirms the findings from the measurements on large wind turbines and a literature study, that infrasound is negligible for this type of wind turbines.

DELTA: Low Frequency Noise from Large Wind Turbines 2008

5 CONCLUSIONS

- Infrasound from wind turbines is below the audible threshold and of no consequence.
- Low frequency noise is normally not a problem, except under conditions of unusually turbulent inflow air

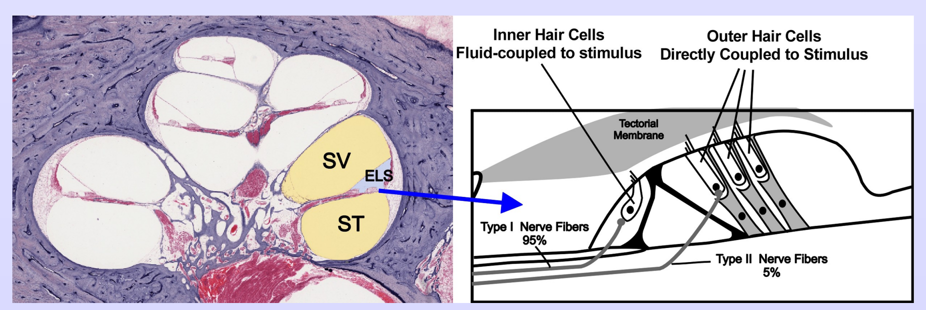
Leventhall G. Canadian Acoustics 2006; 34:29-36.

"Renewable UK", the website of the British Wind Energy Association use this quotation from 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.*

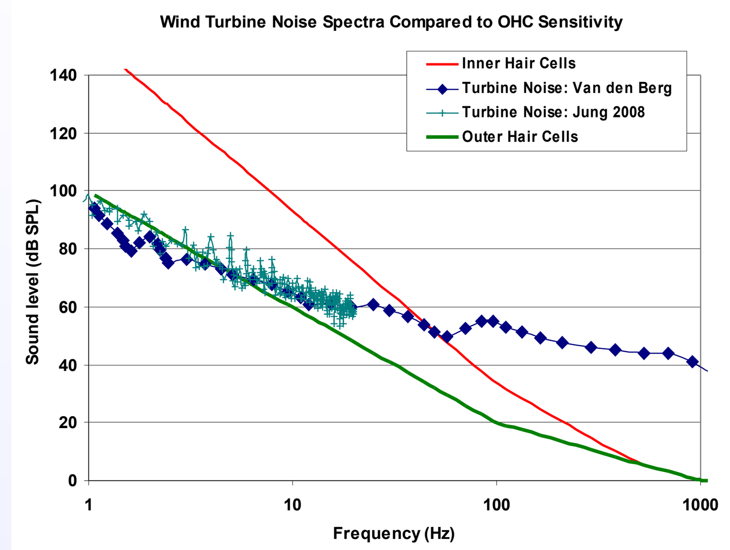
Hearing is mediated by the inner hair cells which are insensitive to low frequencies



The inner hair cell stereocilia do not contact the tectorial membrane, making them fluid-coupled and sensitive to stimulus velocity (*Cheatham and Dallos, JASA 2001;110: 2034*). As a result the inner hair cells rapidly become less sensitive as stimulus frequency is lowered, as shown by the red line on the graph at the top of this column. As we "hear" through our inner hair cells, human hearing sensitivity is comparable to the calculated IHC sensitivity.

This Histological image courtesy of Saumil Merchant, MD, Otopathology Laboratory, Massachusetts Eye and Ear Infirmary and Harvard Medical School, Boston.

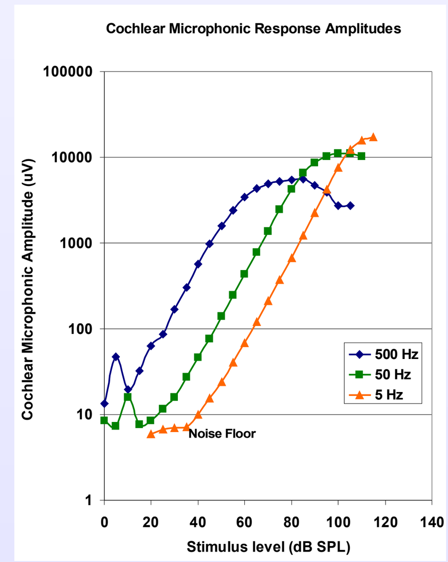
BUT, the Outer Hair Cell stereocilia contact the tectorial membrane, so they are more sensitive to low frequencies and respond at the levels generated by wind turbines



The input sensitivity of outer hair cells (OHC: green) and inner hair cells (red: *adapted from Cheatham and Dallos, JASA 2001;110: 2034*) are compared with measured wind turbine spectra.

Sound frequencies between ~5Hz and ~50 Hz, although at too low a level to be heard, are at high enough level to stimulate the outer hair cells.

Cochlear microphonic measurements (originating from the OHC) show the ear is very sensitive to infrasound

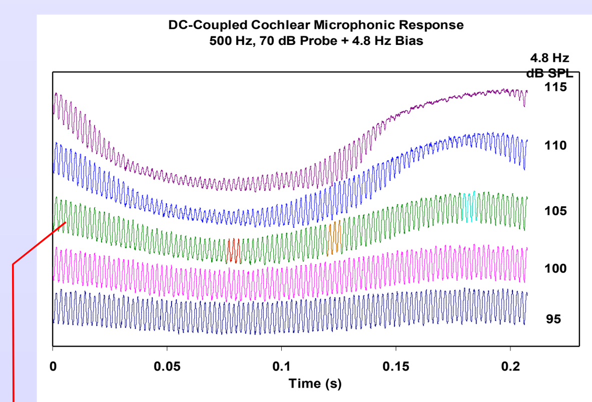


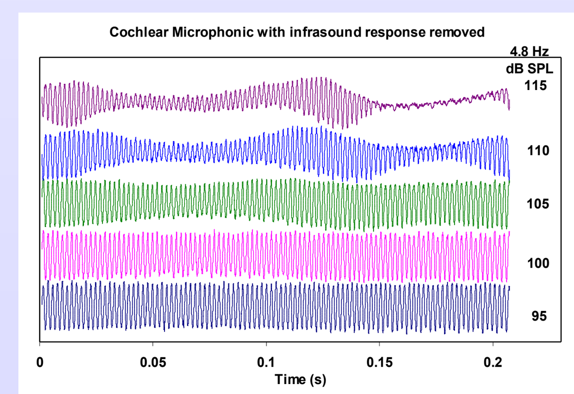
Cochlear microphonic recordings, from a pipette inserted into scala media of the 3rd turn of the guinea pig cochlea show responses to stimuli of 5 Hz. Approx. 37 dB higher sound level is required to generate 100 µV at 5 Hz vs 500 Hz.

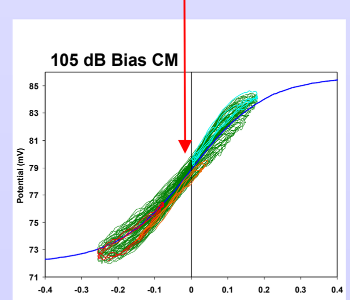
However the maximum response amplitude is over 3x greater for the 5 Hz infrasound (17.3 mV max) than it is at 500 Hz (5.5 mV max).

This confirms the high sensitivity of the outer hair cells to infrasonic stimuli.

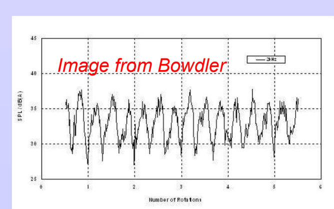
Infrasound effects on OHC function will influence IHC responses: Amplitude Modulation with Biologic Origins





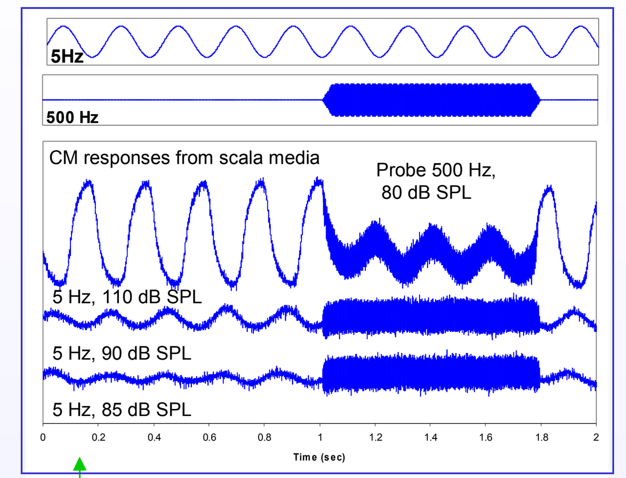


DC-coupled CM recordings (left) in response to combined 4.8 Hz and 500 Hz stimuli show responses to both stimulus components. Changes in the 500 Hz CM waveform are consistent with the bias tone driving the response up and down the cochlear "transducer curve", as shown at the left for the 105 dB bias level. The right panel shows the 500 Hz response with the calculated bias response component removed. This shows a waveform analogous to the expected stimulation of the IHC, which includes amplitude modulation and distortion. Thus, while IHC and hearing may be insensitive to the infrasound itself, sensations may be disturbed by modulation or distortion of responses to higher frequency elements. This modulation is completely of biologic origins and cannot be measured with a sound level meter.
See also poster # 96 Lichtenhan, Guinan & Shera.



Although "amplitude modulation" from wind turbines has been reported as bothersome, this is generally thought to be from the modulation of heard sounds that are recorded as the fluctuation of A-weighted levels with a sound level meter (see example at left). The contribution of biological modulation of the type described above has received virtually no consideration, and is a likely contribution to the disturbances caused by wind turbine noise.

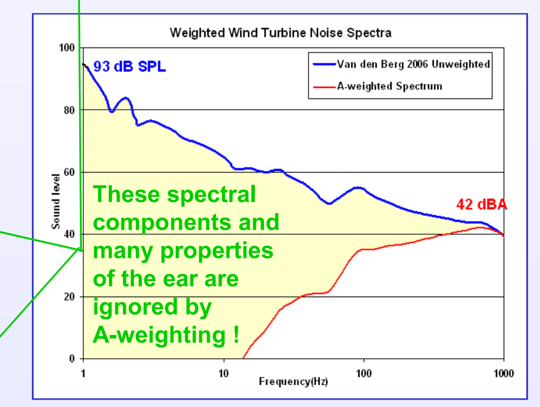
Cochlear Microphonic Responses to Infrasound are Suppressed by Sounds of Higher Frequency



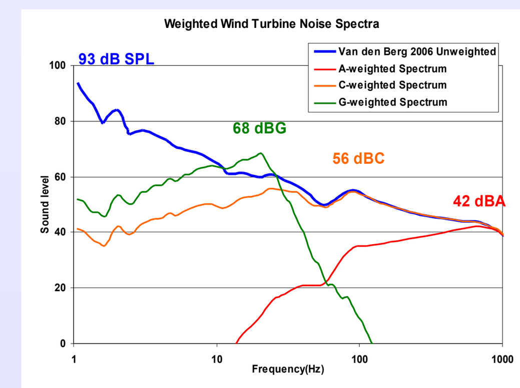
CM responses to infrasound recorded in endolymph of the third turn of the guinea pig cochlea are suppressed by the presence of higher frequency sounds. This is comparable to the previously-reported CM interference phenomenon *(Wever at al., 1940; Cheatham & Dallos 1982)* .

This suggests that the physiologic response to infrasound may be maximal when heard under quiet conditions, such as may occur in a quiet bedroom in the vicinity of a wind turbine.

A-weighted Measurements Underestimate whether Wind Turbine Sounds Affect the Ear



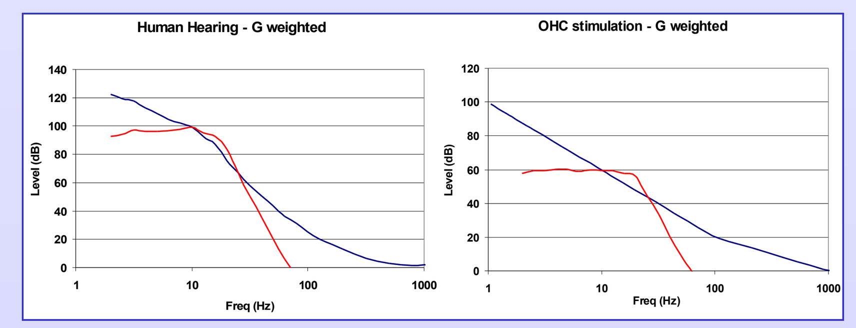
Almost all reported wind turbine noise measurements are A-weighted to reflect how the sound is heard by humans. Based on A-weighted measurements (~40 dB A), wind turbine noise is compared to "the hum of a refrigerator", the "rustling of leaves" or "a quiet bedroom".
If elements of the ear (such as the OHC) are substantially more sensitive than is hearing, then making judgments about whether the sound can affect the ear, based on A-weighted measurements, is totally inappropriate.



There remains no consensus on how turbine sound should be measured. The sound level depends highly on how the measurement is weighted. The peak spectrum level for this example varies from 93 dB SPL (unweighted) to 63 dB G, 56 dB C and to 42 dB A.

The wind turbine industry almost exclusively uses dB A measurements to report sound levels.

G-weighted sound measurements give a better representation of whether the infrasound affects the ear



G-weighted measurements reflect the infrasound content of the sound. Humans can hear sound at approximately 95 dB G, which compares to the "plateau" when the human audibility curve is G-weighted. G-weighting of the OHC sensitivity curve suggests sounds of

60 dB G will stimulate the OHC.

At typical setback distances, most large turbines produce sound levels considerably above 60 dB G.

CONCLUSIONS

1) The inner ear is sensitive to infrasound.
2) The low frequency and infrasound components of wind turbine noise that are below the level that can be heard are well above the level necessary to stimulate the outer hair cells in the ears of humans living nearby.
3) The concept that "What you can't hear, can't affect you" is invalid.
4) Although there is no evidence that the sounds from wind turbines cause damage to the ear, the sound levels generated are of "physiologic significance".
5) A-weighted measurements of wind turbine noise misrepresent whether that noise can affect people. Weighting the sound spectrum based on hearing does not give a valid indication of whether the sound affects components of the ear other than the inner hair cells.