VOLUME 8, ISSUE 2 APRIL 2012

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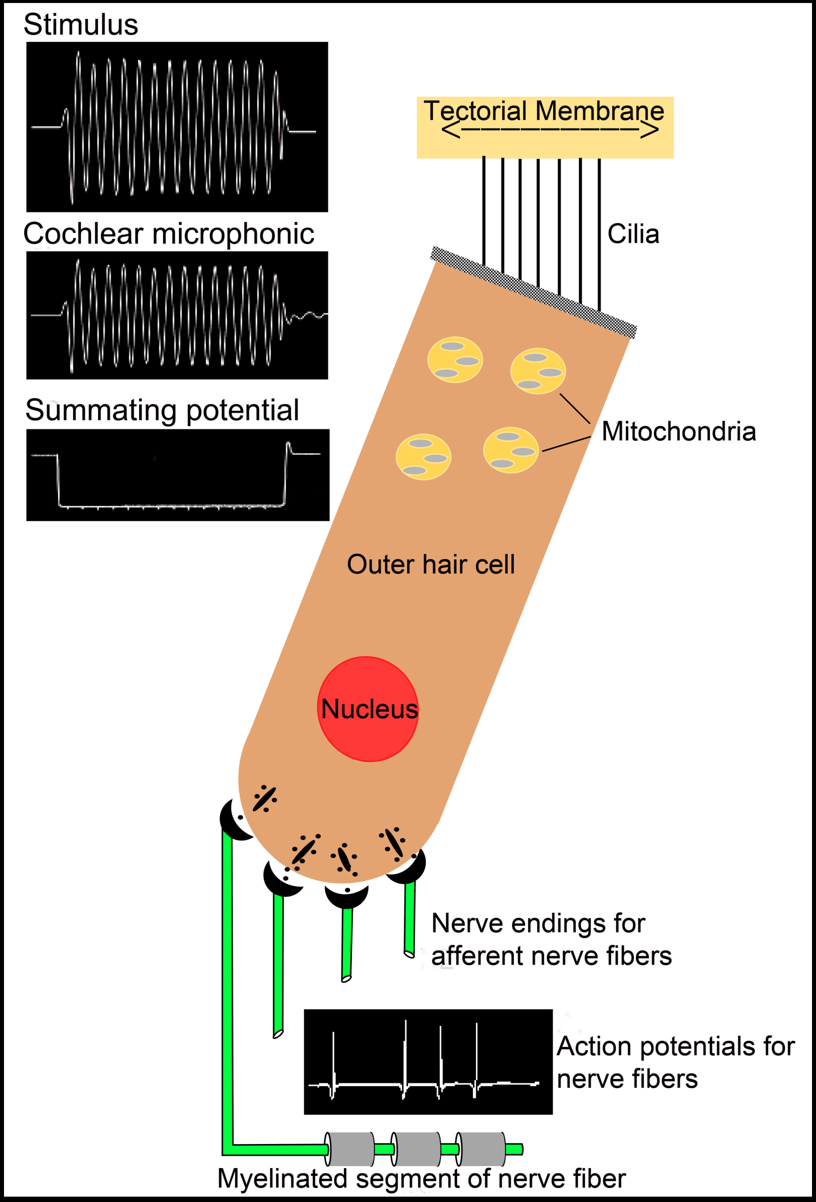

A publication of the Acoustical Society of America

Psychological and Physiological Acoustics

WIND TURBINES AND GHOST STORIES: THE EFFECTS OF INFRASOUND ON THE HUMAN AUDITORY SYSTEM

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Introduction

Climate change and fossil fuel depletion have pushed many countries to seek and invest in alternative clean energy sources, such as wind energy. By converting kinetic energy from the wind into mechanical or electrical energy, wind farms in California, for example, power nearly 850,000 households each year, while producing negligible green house gases and contributing little to water pollution[1] (see Fig. 1). Nevertheless, several ecological and environmental concerns remain. High levels of infrasound and low frequency sounds generated by wind turbines pose a potentially serious threat to communities near wind farms. Wind energy companies remain largely dismissive, claiming that wind turbine noise is subaudible, undetectable by humans, and therefore presents minimal risk to human health. However, various cochlear microphonic, distortion product otoacoustic emission, and functional magnetic resonance imaging (fMRI) studies have demonstrated the detection of infrasound by the human inner ear and auditory cortex. Additional psychosomatic stress and disorders, including the "wind turbine syndrome" and paranormal experiences, are also linked to infrasound exposures.[2,3] With wind turbines generating substantial levels of infrasound and low frequency sound, modifications and regulations to wind farm engineering plans and geographical placements are necessary to minimize community exposure and potential human health risks.

"…studies provide strong evidence for infrasound impact on human peripheral and central auditory responses."

Infrasound definition

It is popular belief that the audio frequency range of human hearing is from 20 to 20,000 Hz and that anything beyond these limits is undetectable by humans. Infrasound is the term that describes the "inaudible" frequencies below 20 Hz. Such a belief is based on the steep slope of hearing thresholds toward the lower end of the human hearing range.[4,5] At 1 kHz, the sound pressure level (SPL) necessary to perceive a 10 phon sound is 10 dB SPL. At 20 Hz, the minimum SPL for 10 phon sound perception has increased to about 84 dB SPL. The phon is a unit that describes perceived loudness level. With decreasing frequencies, the SPLs necessary for sound perception increase rapidly, making very low frequencies at a normally audible intensity more difficult to detect than higher frequencies of the same intensity. Humans' lack of sensitivity to low frequencies is also reflected in the compression of hearing thresholds. At 1 kHz, the SPLs capable of triggering hearing range from 4 to more than 100 dB SPL, exceeding 100 dB in span and increasing at 10 dB/phon. In contrast, the SPL range at 20 Hz is from approximately 80 to 130 dB SPL, spanning only about 50 dB and increasing at 5 dB/phon.[4] In other words, a relatively small increase in SPL at 20 Hz would

Fig. 1. San Gorgonio Pass Windfarm in Riverside County, California. With more than 2,000 wind turbines installed, this windfarm produces enough electricity to power Palm Springs and the entire Coachella Valley.[28] Photograph by Annie Chen

change the perception of this tone from barely audible to very loud. On the other hand, perceivable changes in loudness level at 1 kHz would require larger changes in SPL. The combination of SPL threshold increase and range compression results in poor intensity discrimination at low-frequencies in most people.

However, this audio frequency range is misleading and variable, as inter-individual differences in hearing sensitivity allow some people to detect the "inaudible." Human hearing thresholds have been reported for frequencies from slightly below 20 Hz to as low as 2 Hz in some cases.[6,7] Furthermore, humans encounter and detect many high level infrasound sources on a regular basis, despite their high thresholds.[5] Auditory cortical responses and cochlear modulations to infrasound exposure have also been observed, despite the subjects' lack of tonal perception.[8,9] These studies provide strong evidence for infrasound impact on human peripheral and central auditory responses.

Infrasound impact on inner ear responses

While normal sound perception depends on inner hair cell (IHC) function, human sensitivity to infrasound and low frequencies is thought to rely heavily on outer hair cells (OHCs).[10] Such differential sensitivity between inner and outer hair cells stems from their distinct relationship to the surrounding inner ear structures. Although IHCs and OHCs both sit atop the basilar membrane, the hair (stereovillar) bundles of the OHCs are embedded in the overlying tectorial membrane, unlike those of the IHCs. Instead, IHC hair bundles are bathed in endolymphatic fluid within the subtectorial space and depend on this fluid movement ("squeezing waves") for their stimulation.[11] Mechanical energy must be transferred from the basilar and tectorial membranes to the endolymph to displace the IHC hair bundles. Basilar membrane velocity, however, decreases with decreasing stimulus frequency.[12] At infrasonic frequencies, the low fluid velocity may effectively eliminate IHC hair bundle displacement by fluid motion, rendering IHCs insensitive to infrasound.

In contrast, OHC stereovilli are stimulated directly by the motion of the basilar membrane relative to the tectorial membrane, as they are embedded in the overlying tectorial membrane. The vibrational amplitude of the basilar membrane is proportional to sound pressure level and inversely proportional to frequency.[11–13] OHCs' direct coupling to tectorial membrane movements results in its maintained sensitivity to low-frequency sounds; whereas IHCs' indirect coupling to velocity through fluid movements results in lowered sensitivity. As low-frequency sounds generate significant basilar membrane displacements but low basilar membrane velocities, OHCs are selectively stimulated over IHCs. Furthermore, low-frequency sounds generate minimal endolymphatic viscous forces, allowing maximal stretching of stereovillar tip links for OHC depolarization.[14] It is important, therefore, to keep in mind that high-level, low-frequency stimuli can result in large shearing forces on the OHC stereovilli, but minimal fluid-coupled displacements of IHC stereovilli.

Low-frequency induced OHC intracellular depolarization can be measured as an extracellular voltage change, namely the cochlear microphonic (CM). At 10 Hz (90 dB SPL), CM amplitudes exceed that of the IHC intracellular potentials as a result of basilar membrane displacement.[10,15] CM generation in response to this 10 Hz tone provides concrete evidence for OHC sensitivity to infrasound in the guinea pig. Meanwhile, large CMs generated by OHCs at 40 Hz (112 dB SPL) can electrically stimulate the IHCs to activate type I afferent fibers in the spiral ganglion.[15,16] While type I afferent activation by infrasound has not yet been extensively studied, these data suggest that infrasound has the potential to induce suprathreshold depolarization in IHCs and type I afferent fibers, through large CMs. Subsequent transmission and interpretation of type I afferent signals in the brain would be especially interesting to examine.

In addition to CMs, distortion product otoacoustic emissions (DPOAEs) have also demonstrated human inner ear sensitivity to infrasound. DPOAE recordings allow non-invasive, indirect evaluations of cochlear amplifier characteristics. To elicit DPOAEs, two different pure tones (primaries), f_1 and f_2, are introduced into the ear by placing into the ear canal a sound probe containing two miniature speakers. As the primaries-generated traveling waves propagate along the basilar membrane, they interact and produce additional traveling waves.[17] These waves propagate out of the inner ear, generating DPOAEs that are recorded by a microphone in the sound probe. The most prominent and easily measurable DPOAE in humans and other animals is the cubic difference distortion product, $2f_1$-f_2, typically produced by primary tone ratios (f_2/f_1) between 1.2 to 1.3.[18]

Hensel *et al.* (2007) used primaries of f_1=1.6 and f_2=2.0 kHz (f_2/f_1=1.25) at L_1=51 and L_2=30 dB SPL for their DPOAEs recordings.[8] With the primaries within the normal human audio frequency range, the returning DPOAE represents a typical operating point of the cochlear amplifier. Infrasonic biasing tones (f_b) of 6 Hz, 130 dB SPL and 12 Hz, 115 dB SPL were then introduced and resulting DPOAEs were recorded. When compared to the primaries-only-generated DPOAE pattern, f_b-generated DPOAEs showed significant changes in amplitude and phase due to the shifting of the cochlear amplifier operating point. Since the f_b-generated DPOAE pattern changed relative to the pattern evoked by the primaries-only-generated DPOAES, it may be then concluded that the infrasonic biasing tones had an observable impact on inner ear function.

High level biasing tones provide large vibrational amplitudes that can alter the movement of the cochlear partition, or net pressure across it. The induced pressure gradient in turn shifts the mean position (a DC shift) of the basilar membrane. Such a phenomenon parallels the slow motility mechanism of OHCs. Just as OHC soma contractions alter the dimensions of the subtectorial space to enhance or reduce hearing sensitivity, the shift in basilar membrane position also changes subtectorial volume and adjusts hearing sensitivity. In another words, the gain of the cochlear system can be affected by high level infrasound. Moreover, the modulations seen in f_b-generated DPOAEs reflect differential traveling wave interactions as the result of basilar membrane displacement.

Although the SPLs used for the low-frequency biasing tones approached the pain threshold for human hearing at 1 kHz, the biasing tones did not damage the subjects' cochlear integrity, as shown by consistent primaries-generated DPOAEs before and after biasing tone presentations. None of the subjects reported painful pressure at the eardrum during the experiment. While the biasing tones' high SPLs create large pressure differences in the ear, the sensation of pain may have been reduced by the tones' low vibrational velocity. It was also reported that some subjects perceived a "weak but clearly audible sound sensation, described as humming" but not a "tonal audible stimulus."[7,8,19] The absence of a clear pure-tone percept suggests that infrasonic frequencies do not adequately stimulate the IHCs and hence may not be the sources of the humming. Rather, the source of this percept is likely to be the harmonics of the biasing tone.[20]

Infrasound processing by the auditory pathway

An fMRI study by Dommes *et al.* offers additional insight to infrasound responses in humans.[9] When presented with tones of 12 Hz at 110 and 120 dB SPL, the subjects showed bilateral activation in the primary and secondary auditory cortices (superior temporal gyrus, Brodmann's Area 41, 42, 22). The subjects were also exposed to tones in the human audible frequency range, 500 Hz at 105 dB SPL and 48 Hz at 100 dB SPL. The cortical sites activated for all these frequencies were similar, suggesting that infrasound can have a major impact on brain activation via the auditory pathway. When the 12 Hz tone was reduced to 90 dB SPL, the auditory cortex showed no significant activity, except in one subject. This observation supports the idea of inter-individual differences in low-frequency sensitivity.

Intrinsic noise of fMRI machines can present severe experimental constraints. The scanner noise spectra showed frequencies from 3-10 Hz and 50-900 Hz at levels between 60-75 dB SPL and 60-80 dB SPL, respectively. While infrasound noise remained estimated below threshold,[19] noise between 50-900 Hz was audible and may have affected brain activities. However, Dommes *et al.* believe that the auditory cortex can distinguish and dismiss such background noise.[9] Infrasonic tones must also be presented at high levels in order to overcome fMRI machine background noise. At high levels, the tones produce increased harmonic distortion resulting in high level and more easily detectable harmonics that can potentially alter fMRI results. To evaluate the effects of harmonics, a 36 Hz tone (third harmonic) at 70 dB SPL was presented as a fundamental frequency to the subjects. Auditory cortical activation was observed, though noticeably less than that evoked by a 12 Hz tone at 120 dB SPL. Dommes *et al.* concluded that infrasonic frequencies themselves play significant roles in activating the auditory cortex.[9]

Infrasound exposure on physical and psychological health

Although current research provides no conclusive evidence for infrasound hearing perception by humans, it is nevertheless a worthy exercise to investigate infrasound sources in the immediate environment, as they may contain detectable harmonics. Typical infrasound sources include ocean waves, thunder, wind, machinery engines, slow speed fans, and driving a car with open windows.[5,19] As pure tones are rarely generated in nature, these infrasonic sources typically generate multiple harmonic components and other background noise. It is not unlikely for humans to be exposed to high levels of infrasound. For example, a child on a swing may experience infrasound around 0.5 Hz at 110 dB SPL.[5]

One of the most heavily studied infrasound sources is wind farms. Many wind turbine companies claim that an operating wind farm produces negligible "whooshing" sounds that are comparable only to a kitchen refrigerator around 45 dB SPL.[1,21] However, these claims are based on A-weighted sound analysis, which removes all infrasound components from wind turbine broadband noise. A-weighted filters are inadequate evaluations because they assume human insensitivity to infrasound. Wind turbine spectral analysis by Jung and Cheung has revealed substantial noise levels between 60 to 100 dB SPL for frequencies below 20 Hz.[22] As demonstrated by CMs, DPOAE modulations, and fMRI studies, high levels of infrasound can alter cochlear function and activate the auditory cortex. Potential long term changes in brain activity by nearby wind farms have raised serious concerns. Some physical and psychological health risks from infrasound exposures include the "wind turbine syndrome" and paranormal experiences.[2,10, 23, 24]

Symptoms of the wind turbine syndrome include sleep disturbance, headache, annoyance, irritability, and chronic fatigue. The symptoms often surface when one is close to wind turbines, or an infrasound source, and disappear when the person moves away. As reported, a family exposed continuously to 10 Hz at 35 dB SPL produced by a boiler house complained of bodily pains, increased annoyance, and difficulties sleeping.[5] This family's high sensitivity to a supposedly subthreshold stimulus supports the notion that inter-individual differences are real and that some individuals are more sensitive and susceptible to the effects of low level infrasound than others. In another study, Pedersen *et al.* interviewed 70,000 adults living within 2.5 km of wind farms.[3] They found that adults exposed to levels of A-weighted noise of 40-50 dB SPL reported higher levels of annoyance than those exposed to levels below 40 dB SPL. Moreover, 12% of the subjects exposed to noise at 40-45 dB SPL reported feeling "very annoyed" versus only 6% from subjects exposed to 35-40 dB SPL; in these cases, individual psychological distress due to wind turbine noise is evident. As audible noise levels increase with increasing proximity to wind turbines, the levels of the infrasonic components also increase. Most subjects described the noise as "swishing/lashing," rather than a pure tone sensation. The discontinuity in sound perception can be attributed the inner ear's increased sensitivity to the infrasonic harmonics, as suggested by Hensel *et al.*'s study.[8] When compared to road traffic noise of similar levels, the subjects reported higher annoyance levels from wind turbines. The high annoyance levels are in part due to the ubiquitous presence of wind turbine sounds throughout the day and night, unlike the road traffic noise which abated at night. Additionally, the inherent, high levels of infrasound in wind turbine noise may also modulate brain activity and increase annoyance levels.

In his famous "ghost-buster" study, Tandy recorded a continuous infrasound emission in a 14th century cellar near Coventry University, England.[2] The cellar has been rumored to be haunted since 1997. Various local visitors reported "very strong feeling of presence," "cold chill," and apparitions upon entering the cellar. Moreover, tourists who have never heard of the rumors also reported paranormal experiences. Tandy's previous study in a supposedly haunted laboratory revealed a steady 18.9 Hz emission by a laboratory machine.[24] Once the machine was turned off, reports of paranormal sensations and sightings also ceased. Assuming a similar phenomenon in the cellar, Tandy used broadband sound level meters and recorded a distinct 19 Hz spectral peak in the ambient noise at 38 dB SPL. Other background infrasound signals were also recorded at very low levels between 7-30 dB SPL. Given the variable sensitivities to ultra-low frequencies demonstrated by Dommes *et al.*,[9] the 19 Hz may have had an effect on sensitive visitors and evoked abnormal experiences.

Since the 19 Hz was significantly below its audible threshold, visitors' paranormal experiences could be due to changes in brain activities, despite the absence of tonal perceptions. It is known that temporal lobe epilepsy patients suffer from high risks of depression, anxiety, irritability, insomnia, and psychosis.[25,26] This suggests that hyper or abnormal activity patterns in the temporal lobe, which includes the primary and secondary auditory cortex, could be linked to the psychiatric symptoms observed in the wind turbine syndrome and paranormal experiences.

Conclusions and future directions for infrasound research

Based on CM and DPOAE modulation studies, infrasonic frequencies can have clear effects on human cochlear state and function. Contrary to the belief that the inner ear does not register infrasound, it was found that infrasound can actually be detected by the OHCs. As OHC slow motility controls hearing sensitivity, the responsiveness of these sensory cells to infrasound could potentially enhance one's ability to perceive infrasound's higher harmonics. Whether OHC-generated CMs can trigger spike generation in IHCs' type I auditory nerve fibers, resulting in direct perception of infrasonic frequencies, is a major research focus today. Infrasound induced OHC activation of auditory nerves presents an alternative pathway of focus, as about 5% of all type I afferent fibers synapse with OHCs.[26] High levels of infrasound have been shown to induce shifts in the basilar membrane position, modulating DPOAE patterns. The shift in basilar membrane parallels the function of OHC slow motility by altering subtectorial space. As changes in subtectorial space affect IHC sensitivity, Hensel *et al.* concluded that infrasound itself can affect the overall gain of the cochlear system.[8]

Knowledge gaps between changes in cochlear function, auditory cortical activity, and sound perception remain. As *in vivo* electrophysiology of human auditory afferent fibers is ethically unacceptable, self-reported sound perceptions and fMRI scans dominate current experimental efforts. While Dommes *et al.* showed significant auditory cortical activity in response to infrasound,[9] additional studies are needed to corroborate their findings. For example, activity in primary somatosensory cortex (Brodmann's Area 2, 3) should be examined and compared to that in the auditory cortex. This would reveal whether the auditory or vestibular pathway plays the more important role in human infrasound detection. In addition, subjects' hearing perceptions during fMRI-infrasound scans should be reported, as done by Hensel *et al.*[8] Since auditory cortical activity increased significantly in response to a 12 Hz tone compared to its lower-level 36 Hz harmonic, infrasound detection in humans may be more common than previously thought. In future experiments, should the subjects report tonal or humming perceptions, along with pronounced auditory cortical activities, then it may be that infrasound itself triggers the perception, as opposed to its harmonics. If the subjects do not report any perceptions, auditory cortical activity could be considered unrelated to the stimulus.

Psychosomatic health risks have been proposed to be the result of infrasound exposure, as changes in temporal lobe activity have been linked to several psychiatric disorders. With nearby communities reporting annoyance toward wind turbine noise, further studies are needed to examine the effects of wind farms on the quality of life in sensitive individuals. Long-term studies on wind turbine noise exposure are also needed. As wind energy is widely accepted for its promising role in clean energy production, putting a hold on wind farm development is highly unlikely. For now, engineering efforts and isolated geographical placements of wind farms serve as the best methods for minimizing community exposure to substantial and potentially harmful levels of wind turbine noise.**AT**

References

1 American Wind Energy Association (AWEA), "Wind Turbines and Health," http:// www.awea.org/learnabout/publications/upload/Wind-Turbines-and-Health-Factsheet_WP11.pdf.

2 V. Tandy, "Something in the cellar," J. Soc. Psychical Res. **64.3**(860), 129–140 (2000).

3 E. Pedersen, F. van den Berg, R. Bakker, and J. Bouma, "Response to noise from modern wind farms in the Netherlands," J. Acoust. Soc. Am. **126**(2), 634–643 (2009).

4 ISO: 226, 2003. Acoustics—normal equal-loudness contours (International Organization for Standardization, Geneva, 2003).

5 G. Leventhall, "What is infrasound?" Progress in Biophys. and Molecular Biol. **93**, 130–137 (2007).

6 T. Watanabe and H. Møller, "Low frequency hearing thresholds in pressure field and free field," J. Low Freq. Noise and Vib. **9**(3), 106–115 (1990).

7 N. S. Yeowart, M. E. Bryan, and W. Tempest, "The monaural M.A.P. threshold of hearing at frequencies from 1.5 to 100 c/s.," J. Sound and Vib. **6**(3), 335–342 (1967).

8 J. Hensel, G. Scholz, U. Hurttig, D. Mrowinski, and T. Janssen, "Impact of infrasound on the human cochlea," Hearing Res. **223**, 67–76 (2007).

[9] E. Dommes, H. C. Bauknecht, G. Scholz, Y. Rothemund, J. Hensel, and R. Klingebiel, "Auditory cortex stimulation by low-frequency tones—An fMRI study," Brain Res. **1304**, 129–137 (2009).

[10] A. N. Salt and T. E. Hullar, "Responses of the ear to low frequency sounds, infrasound and wind turbines," Hearing Res. **268**, 12–21 (2010).

[11] J. J. Guinan, Jr., T. Lin, and H. Cheng, "Medial-olivocochlear-efferent effects on basilar membrane and auditory-nerve responses to clicks: Evidence for a new motion within the cochlea," in *Auditory Mechanisms Processes and Models*, edited by A.L. Nuttall, T. Ren, P. Gillespie, K. Grosh, and E. de Boer (World Scientific, Singapore, 2006), pp. 3–16.

[12] M. A. Ruggero, N. C. Rich, A. Reico, S. S. Narayan, and L. Robles, "Basilar-membrane responses to tones at the base of the chinchilla cochlea," J. Acoust. Soc. Am. **101**(4), 2151–2163 (1997).

[13] L. Robles and M. A. Ruggero, "Mechanics of the mammalian cochlea," Physiol. Rev. **81**, 1305–1352 (2001).

[14] D. E. Zetes and C. R. Steele, "Fluid-structure interaction of the stereocilia bundle in relation to mechanotransduction," J. Acoust. Soc. Am. **101**(6), 3593–3601 (1997).

[15] I. J. Russell and P. M. Sellick, "Low frequency characteristics of intracellularly recorded receptor potentials in mammalian hair cells," J. Physiol. **338**, 179–206 (1983).

[16] P. M. Sellick, R. Patuzzi, and B. M. Johnstone, "Modulation of responses of spiral ganglion cells in the guinea pig cochlea by low frequency sound," Hearing Res. **7**(2), 199–221 (1982).

[17] L. A. Shaffer, R. H. Withnell, S. Dhar, D. J. Lilly, S. S. Goodman, and K. M. Harmon, "Sources and mechanisms of DPOAE generation: Implications for the prediction of auditory sensitivity," Ear and Hearing **24**, 367–379 (2003).

[18] T. A. Johnson, S. T. Neely, C. A. Garner, and M. P. Gorga, "Influence of primary-level and primary-frequency ratios on human distortion product otoacoustic emissions," J. Acoust. Soc. Am. **119**(1), 418–428 (2006).

[19] H. Møller and C. S. Pedersen, "Hearing at low and infrasonic frequencies," Noise & Health **23**, 37–57 (2004).

[20] D. L. Johnson, "The effect of high-level infrasound," Proc. Conference on Low Frequency Noise and Hearing, 7-9 May 1980 in Aalborg Denmark, 47-60; as cited by H. Møller, C. S. Pedersen, Noise & Health **23**, 37–57 (2004)

[21] Pennsylvania Wind Working Group (PWWG), Wind Energy Myths," Wind Powering America Fact Sheet Series May. http://www.pawindenergynow.org/wind/wpa_factsheet_myths.pdf

[22] S. S. Jung and W. Cheung, "Experimental identification of acoustic emission characteristics of large wind turbines with emphasis on infrasound and low-frequency noise," J. Korean Physical Soc. **53**, 1897–1905 (2008).

[23] N. Pierpont, *Wind Turbine Syndrome: A report on a natural experiment* (K-Selected Books, Santa Fe, 2009); ISBN 0984182705.

[24] V. Tandy, "The ghost in the machine," J. Soc. Psychical Res. **62**(851), 360-364 (1998).

[25] J. Foong and D. Flugel, "Psychiatric outcome of surgery for temporal lobe epilepsy and presurgical considerations," Epilepsy Res. **75**, 84–95 (2007).

[26] M. Pompili, N. Vanacore, S. Macone, M. Amore, G. Petriconi, M. Tonna, E. Sasso, D. Lester, M. Innamorati, S. Gazzella, C. Di Bonaventura, A. Giallonardo, P. Girardi, R. Tatarelli, and E. Pisa, "Depression, hopelessness and suicide risk among patients suffering from epilepsy," Ann Ist Super Sanita **43**(4), 425–429 (2007).

[27] H. Spoendlin, "Neuroanatomy of the cochlea," in *Facts and Models in Hearing*, edited by E. Zwicker and E. Terhardt (Springer, New York) pp. 18–32 (1974).

[28] American Wind Energy Association (AWEA), "Wind Energy Weekly," http://www.awea.org/learnabout/publications/wew/loader.cfm?csModule=security/getfile&pageid =8321#123.

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Peter Narins and friend

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