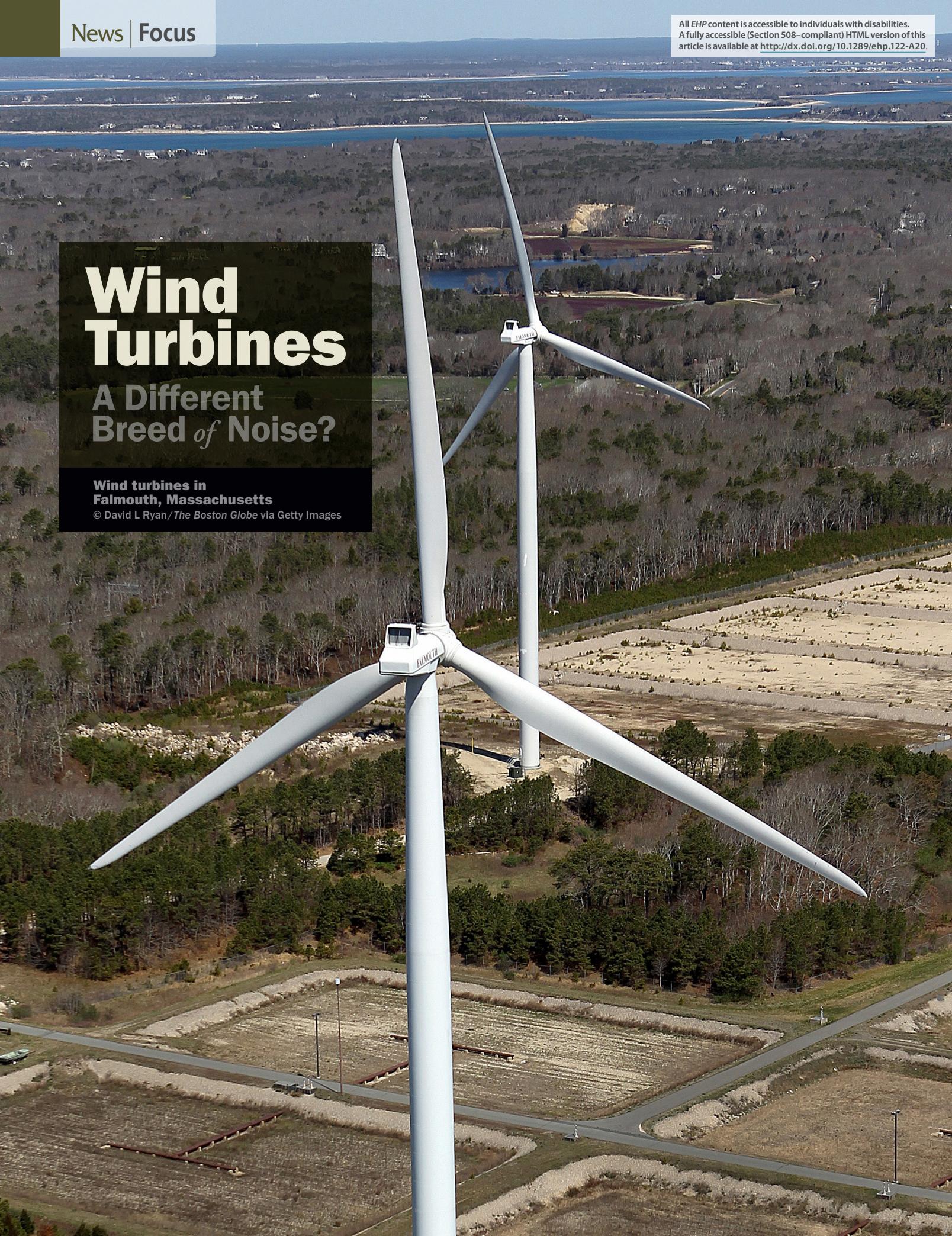
All *EHP* content is accessible to individuals with disabilities. A fully accessible (Section 508–compliant) HTML version of this article is available at http://dx.doi.org/10.1289/ehp.122-A20.

Wind Turbines

A Different Breed *of* Noise?



Wind turbines in Falmouth, Massachusetts

Sue Hobart and her husband built their dream home in 2007 on a quiet, wooded lot outside Falmouth, Massachusetts. Five years later they abandoned it. Less than 1,500 feet from the empty house stands a mammoth wind turbine erected three years ago by Notus Clean Energy. Three blades mounted upon the 262-foot tower sweep an area of the sky equal to 1.3 acres, the size of a football field. They are visible through the forest from the house's meticulously landscaped yard.

But the problem with the property wasn't the degraded view—at least not for the Hobarts. The problem was the noise. Shortly after the turbine switched on in 2010, Sue began experiencing headaches, dizziness, insomnia, and a ringing in her ears. When she noticed the symptoms briefly disappeared during trips out of town, she began attributing them to the arrival of the turbine. Within two years she was ready to leave.

Fellow Falmouth resident Annie Hart Cool can relate. "We live on two and a half acres of land, and we can't use it because of the noise," she says. Cool and her husband live near one of two city-owned turbines installed in 2010 and 2011 that power a nearby wastewater treatment facility, with the excess energy providing a source of revenue for the city. "We were all so excited about it until it turned on, and then we realized we couldn't live with it," Cool says.

In all, 41 Falmouth families have formally complained to city leaders—as have countless other wind-farm neighbors in countries including Australia, Canada, and England. Meanwhile, a small but growing body of evidence has begun to suggest that the health impacts of wind farms can be very real.

Environmental Noise and Health

Researchers have been studying the impacts of environmental noise on human health since at least 1930.[1] Varying degrees of evidence exist for a wide range of nonauditory health effects potentially stemming from noise exposures, including cardiovascular disease,[2,3,4] hypertension,[5,6] stroke,[7,8] diabetes,[9] sleep disturbance,[10] endocrine effects,[11,12] minor psychiatric disorders,[13] and impaired cognitive development.[14]

Yet a March 2013 report by ENNAH, the European Network on Noise and Health, identified 12 areas in which the science of nonauditory health effects of noise still lacks sufficient evidence.[15] These include the extent to which air pollution and other coexposures may contribute to health effects identified in urban noise studies, the comparative health effects of short- and long-term noise exposures, and the relationship between individual health outcomes and noise sensitivity. "Noise sensitivity" has been defined multiple ways but generally refers to an individual's increased likelihood of perceiving noises as annoying—i.e., the person is both more attuned to and more bothered by noise.[16]

Although investigators may not know the exact nature of the relationship between noise and health impacts, or why noise affects some people differently than others, the evidence to date suggests that environmental noise pollution can have serious implications for public health. After air pollution, traffic noise is the second-largest environmental factor affecting human health in the European Union and Norway, according to a 2011 report by the World Health Organization.[17]

The authors of the WHO report estimate that each year, western Europeans lose 1.0–1.6 million disability-adjusted life-years (DALYs) due to traffic noise, a figure thought to be conservative despite accounting for impacts on cardiovascular disease, cognitive impairment in children, sleep disturbance, tinnitus, and annoyance. Sleep disturbance was determined to be responsible for the largest independent share of DALYs lost (903,000), and annoyance (654,000) the next-largest share.[17]

Based on its standing definition of health as "a state of complete physical, mental, and social well-being and not merely the absence of disease or infirmity," the WHO concludes that noise-induced annoyance "may be considered an adverse effect on health."[17] High levels of annoyance have also been shown to lead to stress responses and sleep loss, including attendant symptoms such as headache, gastrointestinal upset, anxiety, fatigue, and hypertension.[18,19,20]

Much of what scientists can conclude today about the health effects of noise in general draws upon studies of transportation noise in urban areas conducted over the past four decades. Among the first to suggest a link between noise and learning impairment was a 1975 study by environmental psychologist Arline Bronzaft.[21] In a New York City elementary school adjacent to an elevated train track, Bronzaft compared the reading scores of children in classrooms facing the tracks to those of children in classrooms on the other side of the building. She discovered that children on the noisy side were nearly one year behind their peers in reading. After two years, once noise-abatement measures had been completed—and other classroom variables held constant—Bronzaft returned to the school and found reading scores on both sides of the building to be at the same grade level.[22]

Today, notwithstanding Bronzaft's groundbreaking early study and New York City's ongoing efforts to mitigate noise pollution, much of the field's cutting-edge research originates outside the United States, where there is more funding and interest surrounding the nonauditory health effects of environmental noise.

For instance, from 2002 to 2006 a landmark study dubbed HYENA (Hypertension and Exposure to Noise near Airports) assessed the relationship between noise from aircraft and road traffic near airports and its implications for hypertension. Researchers measured blood pressure and collected a range of health, socioeconomic, and lifestyle metrics via questionnaire from 4,861 individuals between the ages of 45 and 70. These participants had lived near one of six major European airports for at least five years. The study revealed clear relationships between risk of hypertension and both nighttime aircraft activity and average daily road noise, after adjusting for major confounders including age, sex, body mass index, alcohol intake, and physical activity.[23]

After air pollution, traffic noise is the second-largest environmental factor affecting human health in the European Union and Norway, according to a 2011 report by the World Health Organization. The report authors estimate that each year, western Europeans lose 1.0–1.6 million disability-adjusted life-years due to traffic noise.

Wind Turbines

Large-scale wind turbines are a relatively recent innovation, so the body of peer-reviewed research addressing the potential impacts of their unique brand of sound is sparse and particularly unsettled. Anecdotal evidence strongly suggests a connection between turbines and a constellation of symptoms including nausea, vertigo, blurred vision, unsteady movement, and difficulty reading, remembering, and thinking.[24]

The polarizing issue of wind-turbine noise is often framed one of two ways: Turbines are either harmless,[25] or they tend to

have powerful adverse effects, especially for sensitive individuals.[26] According to Jim Cummings, executive director of the nonprofit Acoustic Ecology Institute in Santa Fe, New Mexico, most of the reports to date that have concluded turbines are harmless examined "direct" effects of sound on people and tended to discount "indirect" effects moderated by annoyance, sleep disruption, and associated stress. But research that considered indirect pathways has yielded evidence strongly suggesting the potential for harm.

Multiple recent studies, including one coauthored by Daniel Shepherd, senior lecturer at New Zealand's Auckland University of Technology, have demonstrated that sleep interference gets worse the nearer residents are to turbines.[20,27] "Sleep is absolutely vital for an organism," he says. "When we lose a night's sleep, we become dysfunctional. The brain is an important organ, and if noise is disturbing its functioning, then that is a direct health effect."

In another recent study, Shepherd made a case for approaching the debate from a social or humanistic standpoint, taking perceived effects seriously even if the potential mechanisms through which they occur remain unclear. Many reasons exist for taking this approach with wind-turbine noise, he wrote.[28]

First is that turbine noise (that is, the aerodynamic noise produced by air moving around the spinning blades as opposed to any mechanical noise from the motor itself) is often deemed more annoying than the hum or roar of transportation noise because of its repetitive nature and high variability in both level and quality—from "swoosh" to "thump" to silence, all modulated by wind speed and direction. This pulsing, uneven quality enables the noise to repeatedly capture the attention and become more difficult to ignore.[29,30]

In addition, unlike vehicle traffic, which tends to get quieter after dark, turbines can sound louder overnight. As Cummings explains, "Often at night, wind shear sets in. This creates conditions with moderate winds at hub height and a sharp boundary layer below which winds are much lower, or even near still." The absolute noise level of the wind farm may be no more than during the day, but it can be 10–20 decibels louder than the quieter nighttime ambient sound levels. This detail has important implications for sleep disruption.

Third, wind turbines generate lower frequencies of sound than traffic. These lower frequencies tend to be judged as more annoying than higher frequencies and are more likely to travel through walls and windows.[31] Infrasound, or sound frequency lower than 20 Hz—inaudible to the human ear—has been associated in some studies with symptoms including fatigue, sleeplessness, and irritability,[32] as well as with changes to the physiology of the inner ear that have poorly understood implications.[33]

Many previous infrasound studies have looked at exposures in populations such as jet pilots and factory workers. Today, Cummings says, "There are some studies looking at whether wind turbine infrasound may have specific qualities that make it more apt to trigger health effects, especially nausea, than 'normal' infrasound from wind or waves or traffic, but these are still very preliminary."

Shepherd points out that residents of the rural and semirural areas—like Falmouth—where turbines are becoming more common may be a self-selected group who are naturally more sensitive to noise than the population at large. As such, they may have greater expectations of quiet and be more aware of noise disturbances, amplifying the potential for health effects related to environmental noise.[34]

"People live in these areas and create their own little patches of paradise, and part of that is the soundscape," Shepherd says. "When an industrial noise source comes in, they get very stressed, because they're losing something that is very dear to them." The negative feelings engendered by this loss of "amenity" (something that once brought joy) can further contribute to a feedback loop of stress, sleep loss, negative emotions, and related health impacts.[10,35]

But are quiet-seeking rural dwellers more prone to report health impacts from new turbines simply because they anticipate a negative outcome? That's the question surrounding the role of the "nocebo" effect—the flip side of placebo, where negative thoughts engender negative outcomes—which is yet another point of contention in the turbine-noise debate. The turbine nocebo effect gained currency worldwide following the March 2013 release of two Australian reports claiming to offer evidence that people who expect adverse effects of turbines—in part as a result of activism by groups such as Australia's Waubra Foundation—are more likely to report having them.

In Cummings' estimation, the two new studies are not as definitive as they purport to be.[36] One, a paper published at the University of Sydney,[37] considered no explanation of health effects other than nocebo. The other, a peer-reviewed study published in *Health Psychology*,[38] reported expectations to have, at most, a very small effect on either the number or severity of reported symptoms.[36] Still, the nocebo effect, whose role has been established in other areas of epidemiology and medicine,[39] may

Turbine noise is often deemed more annoying than transportation noise because of its high variability in both level and quality. Unlike vehicle traffic, which tends to get quieter at night, turbines can sound louder at night. And they generate lower frequencies of sound, which tend to be judged as more annoying than higher frequencies and are more likely to travel through walls and windows.

be impossible to rule out as at least a partial factor in some neighbor responses.

Looking Long Term

The gold standard for proving causality of an exposure is the randomized clinical trial. But when it comes to testing the health effects of noise exposure on humans, such a study design is likely to be not only impractical and difficult to implement, but also unethical.

The next-best evidence would come from longitudinal field research, many researchers agree, such as long-term studies that assess the health of a community before a turbine project is ever proposed and then continue to follow up during operation. Lercher notes that some effects of chronic noise exposure such as elevated blood pressure could take one or two decades to manifest at significant levels.

Most of the studies performed to date around both transportation and wind-farm sources have been cross-sectional, which makes it impossible to assess causality. That's because investigators cannot establish whether the potential cause precedes the potential effect. Lercher stresses that cross-sectional studies purporting to demonstrate a relationship between noise exposures and health effects may be averaging out potential effects that are only visible in some subgroups—e.g., those with certain medical risk factors, or those exposed to the noise for longer than others.

Today, wind turbine noise is attracting ever more interest as a public health issue. That's evident in the offerings at Noise-Con, an annual conference dedicated to noise research, says Purdue University professor Patricia Davies. She chaired the 2013 conference, which was organized in conjunction with the International Wind Turbine Noise Conference in Denver, Colorado. Davis says Noise-Con is beginning to see nearly as many sessions organized around wind turbine noise as in all categories of transportation noise combined. "A few years ago, there were just occasional papers," she says. "Certainly there's more interest right now, because of course there have been a lot more wind turbines built."

Despite increased attention to the issue throughout Falmouth, some residents claim they're hardly better off today than they were when the first turbine switched on in March 2010. Once complaints about the turbines reached a fever pitch, the city voted to limit operation of its two turbines to 12 hours a day, shutting them down between 7 P.M. and 7 A.M. (the Notus Clean Energy unit was not affected).[40] The two city-owned turbines still follow that schedule[41] after surviving a recent petition to decommission them, and in spite of not generating enough income to cover operating costs. Their future remains uncertain.

> High levels of annoyance have been shown to contribute to stress, sleep loss, and attendant health effects such as headaches, anxiety, fatigue, and hypertension.

Nate Seltenrich covers science and the environment from Petaluma, CA. His work has appeared in *High Country News*, *Sierra*, *Earth Island Journal*, the *San Francisco Chronicle*, and other local and national publications.

REFERENCES

1. Smith EL, Laird DA. The loudness of auditory stimuli which affect stomach contractions in healthy human beings. J Acoust Soc Am 2(1):94–98 (1930); http://dx.doi.org/10.1121/1.1915240.
2. Babisch W. Road traffic noise and cardiovascular risk. Noise Health 10(38):27–33 (2008); http://dx.doi.org/10.4103/1463-1741.39005.
3. Hansell AL, et al. Aircraft noise and cardiovascular disease near Heathrow airport in London: small area study. BMJ 347:f5432 (2013); http://www.bmj.com/content/347/bmj.f5432.
4. Correia AW, et al. Residential exposure to aircraft noise and hospital admissions for cardiovascular diseases: multi-airport retrospective study. BMJ 347:f5561 (2013); http://www.bmj.com/content/347/bmj.f5561.
5. van Kempen E, Babisch W. The quantitative relationship between road traffic noise and hypertension: a meta-analysis. J Hypertens 30(6):1075–1086 (2012); http://dx.doi.org/10.1097/HJH.0b013e328352ac54.
6. Dratva J, et al. Transportation noise and blood pressure in a population-based sample of adults. Environ Health Perspect 120(1):50–55 (2012); http://dx.doi.org/10.1289/ehp.1103448.
7. Sørensen M, et al. Road traffic noise and stroke: a prospective cohort study. Eur Heart J 32(6):737–744 (2011); http://dx.doi.org/10.1093/eurheartj/ehq466.
8. Floud S, et al. Exposure to aircraft and road traffic noise and associations with heart disease and stroke in six European countries: a cross-sectional study. Environ Health 12(1):89 (2013); http://dx.doi.org/10.1186/1476-069X-12-89.
9. Sørensen M, et al. Long-term exposure to road traffic noise and incident diabetes: a cohort study. Environ Health Perspect 121(2):217–222 (2013); http://dx.doi.org/10.1289/ehp.1205503.
10. Zaharna M, Guilleminault C. Sleep, noise and health: review. Noise Health 12(47):64–69 (2010); http://dx.doi.org/10.4103/1463-1741.63205.
11. Babisch W. Stress hormones in the research on cardiovascular effects of noise. Noise Health 5(18):1–11 (2003); http://www.ncbi.nlm.nih.gov/pubmed/12631430.
12. Maschke C, Hecht K. Stress hormones and sleep disturbances—electrophysiological and hormonal aspects. Noise Health 6(22):49–54 (2004); http://www.ncbi.nlm.nih.gov/pubmed/15070528.
13. Stansfeld S, Clark C. Mental health effects of noise. Encyclopedia Environ Health 683–689 (2011); http://dx.doi.org/10.1016/B978-0-444-52272-6.00248-8.
14. Clark C, Stansfeld SA. The effect of transportation noise on health and cognitive development: a review of recent evidence. Int J Comp Psychol 20(2):145–158 (2007); http://www.escholarship.org/uc/item/8434889m.
15. Lekaviciute J, et al., eds. Final Report: ENNAH—European Network on Noise and Health. Luxembourg City, Luxembourg:Publications Office of the European Union (2013). Available: http://goo.gl/8IKoXC [accessed 4 December 2013].
16. Shepherd DS, et al. Exploring the relationship between noise sensitivity, annoyance and health-related quality of life in a sample of adults exposed to environmental noise. Int J Environ Res Public Health 7(10)3579–3594 (2010); http://dx.doi.org/10.3390/ijerph7103580.
17. WHO. Burden of Disease from Environmental Noise: Quantification of Healthy Life Years Lost in Europe. Bonn, Germany:World Health Organization European Centre for Environment and Health, World Health Organization Regional Office for Europe (2013). Available: http://goo.gl/MtXWSj [accessed 4 December 2013].
18. Pedersen E, Persson Waye K. Wind turbine noise, annoyance and self-reported health and well-being in different living environments. Occup Environ Med 64(7)480–486 (2007); http://dx.doi.org/10.1136/oem.2006.031039.
19. Bakker RH, et al. Impact of wind turbine sound on annoyance, self-reported sleep disturbance and psychological distress. Sci Total Environ 425:42–51 (2012); http://dx.doi.org/10.1016/j.scitotenv.2012.03.005.
20. Nissenbaum MA, et al. Effects of industrial wind turbine noise on sleep and health. Noise Health 14(60):237–243 (2012); http://dx.doi.org/10.4103/1463-1741.102961.
21. Bronzaft AL, McCarthy DP. The effect of elevated train noise on reading ability. J Environ Behav 7(4):517–527 (1975); http://dx.doi.org/10.1177/001391657500700406.
22. Bronzaft AL. The effect of a noise abatement program on reading ability. J Environ Psychol 1(3):215–222 (1981); http://dx.doi.org/10.1016/S0272-4944(81)80040-0.
23. Jarup L, et al. Hypertension and exposure to noise near airports: the HYENA study. Environ Health Perspect 116(3):329–333 (2008); http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2265027/.
24. Pierpont N. Wind Turbine Syndrome: A Report on a Natural Experiment. Santa Fe, NM:K-Selected Books (2009).
25. Colby WD, et al. Wind Turbine Sound and Health Effects: An Expert Panel Review. Washington, DC:American Wind Energy Association, Canadian Wind Energy Association (2009). Available: http://goo.gl/WhAPY5 [accessed 4 December 2013].
26. Phillips CV. Properly interpreting the epidemiologic evidence about the health effects of industrial wind turbines on nearby residents. Bull Sci Technol Soc 31(4):303–315 (2011); http://dx.doi.org/10.1177/0270467611412554.
27. Shepherd D, et al. Evaluating the impact of wind turbine noise on health-related quality of life. Noise Health 13(54):333–339 (2011); http://dx.doi.org/10.4103/1463-1741.85502.
28. Shepherd D, Billington R. Mitigating the acoustic impacts of modern technologies: acoustic, health, and psychosocial factors informing wind farm placement. Bull Sci Technol Soc 31(5):389–398 (2011); http://dx.doi.org/10.1177/0270467611417841.
29. Pedersen E, Persson Waye K. Perception and annoyance due to wind turbine noise—a dose–response relationship. J Acoust Soc Am 116(6). 3460–3470 (2004); http://dx.doi.org/10.1121/1.1815091.
30. Pedersen E, et al. Response to noise from modern wind farms in The Netherlands. J Acoust Soc Am 126(2):634–643 (2009); http://dx.doi.org/10.1121/1.3160293.
31. Møller H, Pedersen CS. Low-frequency noise from large wind turbines. J Acoust Soc Am 129(6):3727–3744 (2011); http://dx.doi.org/10.1121/1.3543957.
32. Roberts M, Roberts J. Evaluation of the Scientific Literature on the Health Effects Associated with Wind Turbines and Low Frequency Sound. Wood Dale, IL:Exponent, Inc. (20 October 2009). Available: http://goo.gl/R31PVy [accessed 4 December 2013].
33. Salt AN, Hullar TE. Responses of the ear to low frequency sounds, infrasound and wind turbines. Hear Res 268(12):12–21 (2010); http://dx.doi.org/10.1016/j.heares.2010.06.007.
34. Boes S, et al. Aircraft noise, health, and residential sorting: evidence from two quasi-experiments. Health Econ 22(9):1037–1051 (2013); http://dx.doi.org/10.1002/hec.2948.

35. Knopper LD, Ollson CA. Health effects and wind turbines: a review of the literature. Environ Health 10(1):78 (2011); http://dx.doi.org/10.1186/1476-069X-10-78.

36. Cummings J. Do negative expectations cause wind turbine health effects? (AEI analysis and commentary) [weblog entry]. Santa Fe, NM:Acoustic Ecology Institute (22 March 2013). Available: http://aeinews.org/archives/2305 [accessed 4 December 2013].

37. Champan S, et al. Spatio-temporal differences in the history of health and noise complaints about Australian wind farms: evidence for the psychogenic, "communicated disease" hypothesis. Sydney, Australia:University of Sydney School of Public Health (2013). Available: http://ses.library.usyd.edu.au/bitstream/2123/8977/4/Complaints%20FINAL.pdf [accessed 4 December 2013].

38. Crichton F, et al. Can expectations produce symptoms from infrasound associated with wind turbines? Health Psychol; http://dx.doi.org/10.1037/a0031760 [online 11 Mar 2013].

39. Hauser W, et al. Nocebo phenomena in medicine: their relevance in everyday clinical practice. Dtsch Arztebl Int 109(26):459–465 (2012); http://dx.doi.org/10.3238/arztebl.2012.0459.

40. Driscoll SF. Falmouth turbine 'solution' requires state aid. Cape Cod Times, News section, online edition (19 September 2013). Available: http://goo.gl/uTUF7x [accessed 4 December 2013].

41. Hufstader L. Judge orders Falmouth turbine hours cut back. Falmouth Patch, News | Government section, online edition (22 November 2013). Available: http://goo.gl/gVmDD5 [accessed 4 December 2013].