ScienceDirect

Energy Policy
Volume 173, February 2023, 113361

Noise
21.5% mod. annoyed
25.8% very annoyed
No distance stated.
models don't reflect field

Understanding subjective and situational factors of wind turbine noise annoyance

Florian Johannes Yanic Müller [a], Valentin Leschinger [a], Gundula Hübner [a b], Johannes Pohl [a b]

Show more

https://doi.org/10.1016/j.enpol.2022.113361
Get rights and content

Highlights

- Wind turbine noise can affect residents beyond annoyance via stress symptoms.
- Strongly annoyed residents perceive planning process as less fair than others.
- Critical annoyance situations happen mainly while sleeping or trying to sleep.
- Fast wind speeds, wet weather, frost, and fog are associated with annoying noise.

Abstract

I-15

One of the most relevant acceptance factors of local wind turbines (WTs) are noise emissions. To better understand why some residents experience stress effects from wind turbines a field study with strongly annoyed residents (SAR) was conducted. A convenience sample of residents (N = 148) in the proximity of a wind farm in Germany were interviewed using a standardised questionnaire. Objective features, such as number of visible WTs and distance to the nearest WT, could not explain the experienced noise annoyance substantially. Instead, SAR were characterised by a negative perception of both procedural as well as distributive fairness, the assumed decrease of property value due to the WTs, a negative attitude towards the local wind farm (but not to WTs in general), and higher noise sensitivity. Additionally, SAR reported to be affected daily during the night in their bedrooms, while other residents experience annoying situations more likely when they are directly exposed to WTs. Fast wind speeds, wet weather and, occasionally, frost or fog were associated with annoying situations. In accord with recent research, we recommend to increase consideration of participation and fairness in the initial planning of a wind farm to increase acceptance and reduce annoyance. Additionally, to reduce the fear of negative health impacts and to increase acceptance, mitigation measures depending on specific weather conditions seem to be promising.

Introduction

As part of a transition towards renewable energy technologies, many countries plan to increase the amount of land-based wind energy on a large scale. For example, with 220 GW of wind capacity in Europe wind energy accounted for 16% of the EU's electricity consumption in 2020 and is expected to grow by 80–105 GW until 2025 (e.g., WindEurope, 2021). With an increased deployment of wind energy more people will be living in the vicinity of wind turbines (WTs). One major influence on residents' acceptance is the expected or experienced annoyance of WT emissions (Hübner et al., 2019; Pawlaczyk-Łuszczyńska et al., 2018; Pedersen et al., 2009; Pohl et al., 2012, 2018, 2021). Worries about the effects of emissions may initiate negative social dynamics early on and can result in opposition long-term (Baxter et al., 2013; Songsore and Buzzelli, 2014). Residents can be affected, among others, by landscape change, shadow flicker, aircraft obstruction markings, or sound emissions. WT noise appears to be one of the most contentious issues with regard to outcomes residents can be worried about (Hübner et al., 2019; Pohl et al., 2021). Several field studies on sound perception and impacts on WT neighbours are available (e.g., Hansen et al., 2021; Hübner et al., 2019; Jalali et al., 2016; Maijala et al., 2020; Michaud et al., 2016a, 2016b, 2016c; Pedersen et al., 2009; Pohl et al., 2018, 2021; Poulsen et al., 2018a, 2018b; Turunen et al., 2021). However, because of a small prevalence of residents, who are negatively affected by possible stress effects due to WT noise, a direct comparison between them and non-affected residents is missing so far. The present

study aims to provide a better understanding of the causes of negative outcomes for residents by a direct comparison between affected and non-affected residents–in regard to personal as well as situational factors. Finding solutions to mitigate and prevent WT noise annoyance is one step further to increase local acceptability.

According to stress psychological models (e.g., Evans and Cohen, 1987; Lazarus and Cohen, 1977), people are equipped differently to deal with stressors such as noise, depending on situational as well as individual factors. To that effect, while some people can be assumed to be negatively affected by WT noise, and experience stress because of it, others might not be. Hübner et al. (2019) criticise the common assessment of WT noise impacts via a single item measurement of annoyance. They argue that this kind of annoyance measurement can be understood as a measure of attitude rather than a stress indicator. The stress psychological models indicate that an evaluative assessment is only the first step in the process of dealing with a stressor, potentially followed by a stress reaction (Lazarus and Cohen, 1977). Therefore, Hübner et al. (2019) propose to combine the single item measure of annoyance with stress symptoms associated with WTs for a valid indicator of WT impacts. Along this line of reasoning, residents who are at least moderately annoyed, and experience symptoms associated with WTs at least once per month are classified as "strongly annoyed".

The proportions of strongly annoyed residents (SAR) due to WT noise in the vicinity of wind farms are low; between 1.1% and 9.9% SAR were reported (Hübner et al., 2019; Pohl et al., 2018, 2021). The most frequently reported symptoms of WT noise are sleep disturbances (Bakker et al., 2012; Jalali et al., 2016; Pohl et al., 2018; Radun et al., 2019; Turunen et al., 2021; van Kamp & van den Berg, 2018, 2021), while some studies also report psychological distress (e.g., worry, Bakker et al., 2012), effects on mood (e.g., irritability, anger, Pohl et al., 2018), and effects on general performance (e.g., lack of concentration, Pohl et al., 2018; van Kamp & van den Berg, 2018).

By contrasting SAR with not strongly annoyed residents (NSAR), in terms of their personal predispositions and the circumstances under which annoyance occurs, supports the understanding of what leads to annoyance. This understanding is required to recognise negatively affected residents, and acknowledge their experiences and needs (Jenkins et al., 2016; McCauley et al., 2013; Schlosberg, 2013). With that knowledge one can derive insights into how to support them as well as how to protect residents from becoming SAR.

Recent research indicates that WT noise annoyance is influenced by a multitude of factors. Counterintuitively, objective criteria like sound pressure levels (Haac et al., 2019; Hongisto et al., 2017; Michaud et al., 2016c) or distance to the WTs are only related to noise annoyance to a minor degree (Hoen et al., 2019; Hübner et al., 2019; Pohl et al., 2018). Especially for distance the results

are inconsistent: Some authors report small negative correlations (IASS, 2019; Turunen et al., 2021), others find even small positive correlations (Hoen et al., 2019) or none at all (Hübner et al., 2019). Most likely, these divergent results can be attributed to methodological differences. Some studies relied on self-reported distance judgements (IASS, 2019) or distance categories (Hoen et al., 2019; Turunen et al., 2021), while analyses based on exact GIS data did not reveal statistically relevant associations (Hübner et al., 2019).

Subjective factors help to explain why the perceptions and experience of WT noise may differ between residents who live right next to each other. For example, the attitude towards the local WTs (Hoen et al., 2019; Hübner et al., 2019; Pawlaczyk-Łuszczyńska et al., 2018; Radun et al., 2019), noise sensitivity (Hübner et al., 2019; Michaud et al., 2016c; Pedersen and Persson Waye, 2004, 2007; Pohl et al., 2018), as well as aesthetic characteristics (Firestone et al., 2015; Haac et al., 2019; Pedersen et al., 2009) are shown to be correlated with noise annoyance. Furthermore, the perceived process fairness (Hübner et al., 2019) is negatively correlated with annoyance and is considered important for the acceptance of WTs, too (Firestone et al., 2018; Gölz and Wedderhoff, 2018; Reitz et al., 2022).

Apart from these more latent aspects, comparatively few studies investigate the more situational patterns and behaviours, which might affect the perception of WT sounds. Understanding the similarities of situations in which noise annoyance occurs, can help develop mitigation measures that target crucial aspects. Pohl et al. (2018) had their respondents describe a typical situation with WT noise: Noise was mostly experienced during the evening and night while sleeping or during relaxation. The main wind direction, as well as humid weather, and frost were associated with noise. Michaud et al. (2016c) found that highly annoyed residents were more likely to have triple pane windows, and more likely to close their bedroom windows due to WT noise than less annoyed residents, corroborating that noise was relevant in situations associated with sleep. Empirical evidence indicates that the experience of annoying noise can differ between SAR and NSAR, e.g., that cognitive coping responses to noise differ, depending on how annoyed residents were (Pohl et al., 2018). These included that SAR were more likely to report to critically observe the WTs, or that they were less likely to say to have made peace with them. Despite these efforts, a comprehensive comparison between SAR and NSAR has not yet been realised.

Owing to talks to residents and authorities after a previous research project in the region (Hübner et al., 2020), the wind farm Tegelberg was brought to our attention as there were severe conflicts because of WT noise. The wind farm is located in the rural, mountainous area of the Swabian Alb in the German state of Baden-Wuerttemberg. The wind farm belongs to the community Donzdorf, but is positioned right at the border to the neighbouring municipality Kuchen. There are three WTs with

a power of 2.78 MW and total height of 199 m each (GE 2.75–120). At the onset of the investigation, the wind farm was in operation for 31 months (since December 2017).

The case of Tegelberg potentially offered the opportunity to investigate SAR in detail and compare them to NSAR. Comparing both groups within the same setting limits the influence of exterior variables and allows to focus on the differences. The comparison includes physical features, the personal evaluation of the planning and construction of the wind farm, attitudinal aspects, indicators for health, and stress, and situational aspects of noise occurrences. Based on the aforementioned literature we expected SAR, in comparison to NSAR, to hold more negative attitudes towards the local WTs, be more noise sensitive, and perceive the planning process to have been less fair. Furthermore, annoying situations might happen during evening and night hours, and with wet, and freezing weather. Yet, the literature does not give a conclusive answer, whether this is consistent among SAR and NSAR.

Further interdisciplinary measurements were conducted at site, including acoustic, ground motion, and meteorological measurements. These are reported elsewhere (Gaßner et al., 2022).

Section snippets

Methods

The study design was based on the concepts and methodology of environmental and stress psychology (Lazarus and Cohen, 1977) and previous research on stress effects of WTs (Hübner et al., 2019; Pohl et al., 2018). Using a standardised questionnaire, residents of the wind farm Tegelberg were interviewed via telephone by trained students. …

WT annoyance

The majority did hear WT sounds (63.5%). Applying the single item measurement of annoyance, 17.2% of these participants were not at all annoyed by the sounds (scale point 0), 16.1% were slightly

annoyed (scale point 1), 19.4% somewhat annoyed (scale point 2), 21.5% moderately annoyed (scale point 3) and 25.8% very annoyed (scale point 4). Overall, WT noise is rated as somewhat annoying (M = 2.18, SD = 1.46). How annoying the noise is has not changed for residents since the wind farm started to …

Discussion and recommendations

To derive mitigation recommendations, we analysed the circumstances under which residents experienced stress effects caused by WT noise in-depth. Overall, the findings corroborate existing result patterns even in the context of a noteworthy higher proportion of SAR (33.1% at Tegelberg vs. 1.1%–9.9% in comparable studies with similar recruitment methodologies and samples, Hübner et al., 2019; Pohl et al., 2018; Pohl et al., 2021). A comparison between SAR and NSAR revealed a breadth of …

Funding

This study is supported by the Federal Ministry of Economics and Climate Action on the basis of a decision of the German Bundestag (grant 03EE2023A). …

CRediT authorship contribution statement

Florian Johannes Yanic Müller: Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Writing – original draft, Visualization. **Valentin Leschinger:** Formal analysis, Investigation, Writing – original draft. **Gundula Hübner:** Conceptualization, Methodology, Writing – review & editing, Supervision, Funding acquisition. **Johannes Pohl:** Conceptualization, Methodology, Investigation, Writing – review & editing, Supervision, Project administration, Funding acquisition. …

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. …

Acknowledgement

We thank the municipality Kuchen, as well as the Stadtwerke Schwäbisch Hall for their support. We thank the local residents, who supported communication about the survey, and the participants,

with whom we conducted the interviews. Furthermore, we thank Nicole Laurich, Joshua von Ehrenkrook, Antonia Freund, Clara Gunzelmann, Kim-Lara Kristof, Farid Mönkemöller, Thekla Nitzsche, Sara Rieper, Constanze Schäffer, Pia Schulz, and Jenny Widmann for their help in conducting interviews and data entry. ...

Special issue articles Recommended articles

References (64)

R.H. Bakker *et al.*
Impact of wind turbine sound on annoyance, self-reported sleep disturbance and psychological distress
Sci. Total Environ. (2012)

J. Baxter *et al.*
A case-control study of support/opposition to wind turbines: perceptions of health risk, economic benefits, and community conflict
Energy Pol. (2013)

J. Baxter *et al.*
Scale, history and justice in community wind energy: an empirical review
Energy Res. Social Sci. (2020)

S. Breukers *et al.*
Wind power implementation in changing institutional landscapes: an international comparison
Energy Pol. (2007)

N. Dällenbach *et al.*
How far do noise concerns travel? Exploring how familiarity and justice shape noise expectations and social acceptance of planned wind energy projects
Energy Res. Social Sci. (2022)

J. Fields *et al.*
Standardized general-purpose noise reaction questions for community noise surveys: research and a recommendation

J. Sound Vib. (2001)

J. Firestone *et al.*
See me, Feel me, Touch me, Heal me: wind turbines, culture, landscapes, and sound impressions
Land Use Pol. (2015)

L. Gaßner *et al.*
Joint analysis of resident complaints, meteorological, acoustic, and ground motion data to establish a robust annoyance evaluation of wind turbine emissions
Renew. Energy (2022)

S. Gölz *et al.*
Explaining regional acceptance of the German energy transition by including trust in stakeholders and perception of fairness as socio-institutional factors
Energy Res. Social Sci. (2018)

B. Hoen *et al.*
Attitudes of US wind turbine neighbors: analysis of a nationwide survey
Energy Pol. (2019)

View more references

Cited by (23)

Community-based wind energy development does not work? Empirical evidence from residents in Canada and Ireland

2024, Energy Policy

Citation Excerpt :

...Such studies tend to go beyond the perception-focused surveys, observation and interviews which dominate social acceptance research to take such local field measurements as noise, sleep, blood, hair, dead birds or bats and flicker. Yet there are bridging concepts like "annoyance", which connect the two literatures to show that direct physical (often stress-related) responses to turbines are mediated by how annoyed an individual is with a wide range of wind energy development characteristics (e.g., Müller et al., 2023; van den Berg and Tempels, 2022; Michaud et al., 2016). Despite the value of physical variable predictors, the role of perceived aspects of

> WED and the social and planning milieux are shown to be separate and essential for understanding why locals accept are positive about and even support local turbines (Rand and Hoen, 2017)....

Wind energy harvesting with building-integrated ducted openings: CFD simulation and neural network optimization

2024, Energy Reports

Show abstract

Energy enhancement through noise minimization using acoustic metamaterials in a wind farm

2024, Renewable Energy

> *Citation Excerpt :*
>
> ...The incessant push towards alternative energy sources has positioned wind energy as the potential power source to satisfy our ever-increasing energy needs [1–6]. However, wind turbines (WTs), the governing mechanism of wind energy, suffer from excessive noise [7–10]. Specifically, noise annoyance from WTs contributes to adverse health impacts on nearby human habitats [11–14] as well as economic losses due to fears of deprecating nearby property values and obstacles for new and existing projects [15,16]....

Show abstract

Commercial wind turbines and residential home values: New evidence from the universe of land-based wind projects in the United States

2024, Energy Policy

> *Citation Excerpt :*
>
> ...Instead, photo simulations from a relatively small set of prominent viewpoints in communities are provided, and, therefore, home buyers and sellers are left to speculate what views of turbines from their homes might look like. Similarly, the sounds of turbines, especially those at night when the background sounds dissipate (Müller et al., 2023), are not ever simulated at individual home locations, though they are often regulated at those locations (Haac et al., 2019). Providing views, both day and night, from many more viewpoints including homes throughout the community, and simulated sounds from different locations, might help to alleviate the practice of pricing in this risk....

Show abstract

Do concerns about wind farms blow over with time? Residents' acceptance over phases of project development and proximity

2024, Renewable and Sustainable Energy Reviews

> *Citation Excerpt :*
>
> ...A greater proportion of residents with weaker preferences for wind farm development are at earlier phases of project development than strongly supportive respondents (Table 6). This indicates that the planning phase is likely to be an important time to address local concerns [107,53,62,45]. Furthermore, Model 1 in Table 8 also suggests that residents are more likely to be willing to accept projects that are 2–10 km away from their home rather than within a 2 km 'near-neighbour zone' of possible impact [33]....

Show abstract

Dynamics of social acceptance of renewable energy: An introduction to the concept

2023, Energy Policy

Show abstract

View all citing articles on Scopus ↗

ScienceDirect

Hearing Research

Volume 268, Issues 1–2, 1 September 2010, Pages 12-21

Infrasound.

possible influence on ear physiology

Review Article

Responses of the ear to low frequency sounds, infrasound and wind turbines

Alec N. Salt, Timothy E. Hullar

Show more

https://doi.org/10.1016/j.heares.2010.06.007

Get rights and content

Abstract

Infrasonic sounds are generated internally in the body (by respiration, heartbeat, coughing, etc) and by external sources, such as air conditioning systems, inside vehicles, some industrial processes and, now becoming increasingly prevalent, wind turbines. It is widely assumed that infrasound presented at an amplitude below what is audible has no influence on the ear. In this review, we consider possible ways that low frequency sounds, at levels that may or may not be heard, could influence the function of the ear. The inner ear has elaborate mechanisms to attenuate low frequency sound components before they are transmitted to the brain. The auditory portion of the ear, the cochlea, has two types of sensory cells, inner hair cells (IHC) and outer hair cells (OHC), of which the IHC are coupled to the afferent fibers that transmit "hearing" to the brain. The sensory stereocilia ("hairs") on the IHC are "fluid coupled" to mechanical stimuli, so their responses depend on stimulus velocity and their sensitivity decreases as sound frequency is lowered. In contrast, the OHC are directly coupled to mechanical stimuli, so their input remains greater than for IHC at low frequencies. At very low frequencies the OHC are stimulated by sounds at levels below those that are heard. Although the hair cells in other sensory structures such as the saccule may be tuned to

I-16

infrasonic frequencies, auditory stimulus coupling to these structures is inefficient so that they are unlikely to be influenced by airborne infrasound. Structures that are involved in endolymph volume regulation are also known to be influenced by infrasound, but their sensitivity is also thought to be low. There are, however, abnormal states in which the ear becomes hypersensitive to infrasound. In most cases, the inner ear's responses to infrasound can be considered normal, but they could be associated with unfamiliar sensations or subtle changes in physiology. This raises the possibility that exposure to the infrasound component of wind turbine noise could influence the physiology of the ear.

Introduction

The increasing use of wind turbines as a "green" form of energy generation is an impressive technological achievement. Over time, there have been rapid increases in the size of the towers, blades, and generator capacity of wind turbines, as well as a dramatic increase in their numbers. Associated with the deployment of wind turbines, however, has been a rather unexpected development. Some people are very upset by the noise that some wind turbines produce. Wind turbine noise becomes annoying at substantially lower levels than other forms of transportation noise, with the exception of railroad shunting yards (Pedersen and Waye, 2004, Pedersen and Persson Waye, 2007, Pedersen et al., 2009). Some people with wind turbines located close to their homes have reported a variety of clinical symptoms that in rare cases are severe enough to force them to move away. These symptoms include sleep disturbance, headaches, difficulty concentrating, irritability and fatigue, but also include a number of otologic symptoms including dizziness or vertigo, tinnitus and the sensation of aural pain or pressure (Harry,, Pierpont, 2009). The symptom group has been colloquially termed "wind turbine syndrome" and speculated to result from the low frequency sounds that wind turbines generate (Pierpont, 2009). Similar symptoms resulting from low frequency sound emissions from non-wind turbine sources have also been reported (Feldmann and Pitten, 2004).

On the other hand, engineers associated with the wind industry maintain that infrasound from wind turbines is of no consequence if it is below the audible threshold. The British Wind Energy Association (2010), states that sound from wind turbines are in the 30–50 dBA range, a level they correctly describe as difficult to discern above the rustling of trees [i.e. leaves].

This begs the question of why there is such an enormous discrepancy between subjective reactions to wind turbines and the measured sound levels. Many people live without problems near noisy intersections, airports and factories where sound levels are higher. The answer may lie in the high

infrasound component of the sound generated by wind turbines. A detailed review of the effects of low frequency noise on the body was provided by Leventhall (2009). Although it is widely believed that infrasound from wind turbines cannot affect the ear, this view fails to recognize the complex physiology that underlies the ear's response to low frequency sounds. This review considers the factors that influence how different components of the ear respond to low frequency stimulation and specifically whether different sensory cell types of the inner ear could be stimulated by infrasound at the levels typically experienced in the vicinity of wind turbines.

Section snippets

The physics of infrasound

Sounds represent fluctuating pressure changes superimposed on the normal ambient pressure, and can be defined by their spectral frequency components. Sounds with frequencies ranging from 20 Hz to 20 kHz represent those typically heard by humans and are designated as falling within the audible range. Sounds with frequencies below the audible range are termed infrasound. The boundary between the two is arbitrary and there is no physical distinction between infrasound and sounds in the audible ...

Overview of the anatomy of the ear

The auditory part of the inner ear, the cochlea, consists of a series of fluid-filled tubes, spiraling around the auditory nerve. A section through the middle of a human cochlea is shown in Fig. 1A. The anatomy of each turn is characterized by three fluid-filled spaces (Fig. 1B): scala tympani (ST) and scala vestibuli (SV) containing perilymph (yellow), separated by the endolymphatic space (ELS) (blue). The two perilymphatic compartments are connected together at the apex of the cochlea through ...

Mechanics of low frequency stimulation

Infrasound entering the ear through the ossicular chain is likely to have a greater effect on the structures of the inner ear than is sound generated internally. The basic principles underlying stimulation of the inner ear by low frequency sounds are illustrated in Fig. 2. Panel A shows the compartments of a simplified, uncoiled cochlea bounded by solid walls with two parallel fluid

spaces representing SV and ST respectively that are separated by a distensible membrane representing the basilar ...

Cochlear hair cells

When airborne sounds enter the ear, to be transduced into an electrical signal by the cochlear hair cells, they are subjected to a number of mechanical and physiologic transformations, some of which vary systematically with frequency. The main processes involved were established in many studies and were summarized by Cheatham and Dallos (2001). A summary of the components is shown in Fig. 3. There are three major processes influencing the sensitivity of the ear to low frequencies. The first ...

Wind turbine noise

Demonstrating an accurate frequency spectrum of the sound generated by wind turbines creates a number of technical problems. One major factor that makes understanding the effects of wind turbine noise on the ear more difficult is the widespread use of A-weighting to document sound levels. A-weighting shapes the measured spectrum according to the sensitivity of human hearing, corresponding to the IHC responses. As we know the sensitivity for many other elements of inner ear related to the OHC do ...

Conclusions

The fact that some inner ear components (such as the OHC) may respond to infrasound at the frequencies and levels generated by wind turbines does not necessarily mean that they will be perceived or disturb function in any way. On the contrary though, if infrasound is affecting cells and structures at levels that cannot be heard this leads to the possibility that wind turbine noise could be influencing function or causing unfamiliar sensations. Long-term stimulation of position-stabilizing or ...

Acknowledgments

This work was supported by research grant RO1 DC01368 (2005–2010) and KO8 DC 006869 (2004–2010) from the National Institute on Deafness and Other Communication Disorders, National Institutes of Health. ...

Recommended articles

References (96)

J. Ashmore *et al.*
The remarkable cochlear amplifier
Hear. Res. (2010)

M.A. Cheatham *et al.*
Low-frequency modulation of inner hair cell and organ of corti responses in the guinea pig cochlea
Hear. Res. (1997)

I.S. Curthoys
A critical review of the neurophysiological evidence underlying clinical vestibular testing using sound, vibration and galvanic stimuli
Clin. Neurophysiol. (2010)

P. Dallos
Some electrical circuit properties of the organ of Corti. II. Analysis including reactive elements
Hear. Res. (1984)

P. Dallos
Cochlear amplification, outer hair cells and prestin
Curr. Opin. Neurobiol. (2008)

A. Dancer *et al.*
Intracochlear sound pressure measurements in guinea pigs
Hear. Res. (1980)

A. Flock *et al.*
Hydrops in the cochlea can be induced by sound as well as by static pressure
Hear. Res. (2000)

G. Frank *et al.*
The acoustic two-tone distortions $2f_1-f_2$ and f_2-f_1 and their possible relation to changes

in the operating point of the cochlear amplifier
Hear. Res. (1996)

G.W. Harding *et al.*
Effect of infrasound on cochlear damage from exposure to a 4 kHz octave band of noise
Hear. Res. (2007)

J. Hensel *et al.*
Impact of infrasound on the human cochlea
Hear. Res. (2007)

View more references

Cited by (130)

Factors influencing citizens' acceptance and non-acceptance of wind energy in Germany

2018, Journal of Cleaner Production

> *Citation Excerpt :*
>
> ...People tend to associate the term infrasound with negative connotations. The negative effect of the fear of infrasound is in line with previous studies (Knopper and Ollson, 2011; Baxter et al., 2013; Salt and Hullar, 2010). Our results are also in line with Brennan and Van Rensburg (2016) stating that alibi participation has a negative effect on the active acceptance of wind energy....

Show abstract

Public participation in wind energy projects located in Germany: Which form of participation is the key to acceptance?

2017, Renewable Energy

> *Citation Excerpt :*
>
> ...The none-parameter increases significantly, suggesting a decreasing utility for those respondents who fear infrasound from wind turbines. This finding is consistent with other studies [87–89]. In total, all three covariates have an impact on the different participation modes....

Show abstract

Health effects related to wind turbine noise exposure: A systematic review ↗

2014, Plos One

Show abstract

Health effects and wind turbines: A review of the literature ↗

2011, Environmental Health A Global Access Science Source

Show abstract

Health Effects Related to Wind Turbine Sound, Including Low-Frequency Sound and Infrasound ↗

2018, Acoustics Australia

Evaluating the impact of wind turbine noise on health-related quality of life ↗

2011, Noise and Health

View all citing articles on Scopus ↗

SCIREA Journal of Clinical Medicine
ISSN: 2706-8870
http://www.scirea.org/journal/CM
June 16, 2025
Volume 10, Issue 2, April 2025
https://doi.org/10.54647/cm321372

A fundamental basis for all living creatures, *mechanotransduction,* is significantly endangered by periodic exposure to impulsive infrasound and vibration from technical emitters - in particular cardiovascular and embryological functions

Infrasound physiological process

Ursula Maria Bellut-Staeck
Independent Researcher, Germany

Abstract

Mechanotransduction is *the* common basis for all organisms for converting physical forces into biochemical and biological information. Ongoing PIEZO channel research confirms PIEZ0-I and II channels in numerous other tissues including outside the endothelium. The prerequisite for a inflammatory transformation of the endothelium *is chronic oxidative and oscillatory* stress, as vital regulatory processes depend on an *uninterrupted laminar flow in the* capillary system *and the* integrity of the endothelium. Vascular health, in turn, is closely linked to demand-driven NO bioavailability and its homeostasis.

The latest findings on a growing environmental factor show clear signs of an incompatibility between chronic and impulsive low frequencies and a fundamental information pathway of all organisms. The potentially serious consequences of an interaction, e.g., loss of endothelial integrity, increased blood pressure and tissue remodelling of the heart, reduced fertility, stranding`s and death of whales, decline in animal species and insects and reduction in plant

I-17

biomass, have a common basis, which is discussed in this article: *mechanotransduction*. A force that is not demand-oriented can lead to irregular information.

There is an urgent need to reassess the far-reaching effects and consequences of infrasound and vibrations *from technical installations such as biogas plants, heat pumps and* in particular, *large (250 m+) industrial wind turbines* (IWT). *'If you want to discover the secrets of the universe, think in terms of energy, frequencies and vibrations'* (quote from Tesla). Mechanotransduction is a common basis for all life and must be preserved.

Keywords: *mechanotransduction, cardiovascular diseases, embryogenesis, oxidative and oscillatory stress, infrasound and vibration, endothelial integrity, NO homeostasis, PIEZO-channels, biodiversity.*

1. Introduction

For years, researchers have been searching rather unsuccessfully for the pathophysiological mechanism that explains why people living near infrasound-emitting installations exhibit similar symptoms everywhere, domestic animals display conspicuous behaviour and why animals avoid the immediate vicinity of increasingly taller wind turbines or other technical installations that emit infrasound and vibration. The research was for longer times mainly planned, carried out and evaluated by acousticians. Since around 2017, international studies have increasingly pointed to cellular stress effects and serious health impacts from chronic exposure to periodically occurring, low-frequency infrasound and vibrations. The knowledge of the specific properties of this far-reaching environmental factor and the current state of research on endothelial mechanotransduction and PIEZO channels has enabled *a paradigm shift*. The cellular effects could be reclassified.

Ongoing investigations of the PIEZO channel show high concentrations in varying distributions of PIEZO- I and -II channels, even outside the endothelium. The possible effects on the affected organisms are becoming increasingly clear. Sound, whether audible to organisms or not, is subject to the laws of physics.

2. Relevant Foundations

2.1. Structure, Components and Regulation of the Microcirculation System in Mammals

The vascular endothelium serves as *interface* and "*switching point*" between bloodstream and tissue. Endothelial regulation of vasodilation and contraction, vascular permeability and fluid homeostasis, inflammation and immune signalling, are vital for vascular health, which in turn is pivotal to our survival [1]. The endothelium perceives physical and chemical signals from the environment as information and converts them into a response. It consists of the sum of all flat endothelial cells (ED`s), lining all the mammal's vessels - including lymph vessels - as *the body`s largest organ* [2,3]. The ED corresponds in its structure to a somatic cell and is specified for its diverse tasks [3,4]. The surface area of the *endothelium* corresponds approximately to two football pitches – according to new estimates approximately 7,000 square meters for an adult male – and its total weight is estimated at around one and a half kilograms [2]. On the one hand, this enables a nutrient supply that is well adapted to current needs [2,3,4,5], on the other hand, this large surface area also provides a target for *internal and external disruptive factors*. For an overview, which cannot be complete, the complex tasks of endothelial cells are shown in Fig.1. [4].

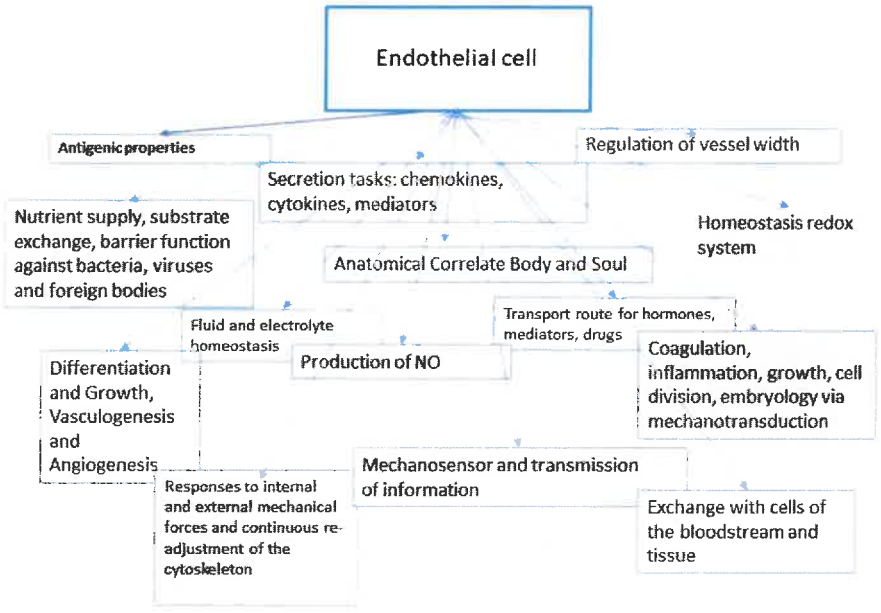


FIG 1: A selection of the most important endothelial functions. Bellut-Staeck UM.2022 [4], translated in English

By regulating the resistance via the upstream arterioles, we physiologically find laminar flow with uniform velocity, strictly bound to vessel size. This is a *crucial precondition* for the diverse and vital tasks of microcirculation and endothelial cells, which take place *in the circuit's low-pressure system* [3,4,6]. Under physical strain, a so-called *capillary recruitment,* according to Moore and Fraser [8], begins by lowering the vascular resistance of upstream arterioles, resulting in a significant increase in the nutrient exchange surface and decrease in the distance between two capillaries [5]. Vascular regulation is controlled by *intrinsic and extrinsic* factors. The autonomic nerve system and vasoactive hormones, e.g., *adrenalin, vasopressin, angiotensin, serotonin,* modulate the intrinsic activity [2,3,7,8]. Vascular segments *are acting in a coordinated manner*, which is attributed to the *Endothelium-derived-hyperpolarising-factor* (*EDHF*) [1]. *EDHF* has a far-reaching effect as vascular response, both upstream and downstream. *Calcium-dependent* activation of potassium efflux by *EDHF* is followed by *hyperpolarisation* with almost simultaneous transmission of electron transfer within the vessel wall via *gap junctions* [11]. This reaction is comparable to *a "school of fish"*, very fast and synchronized [12]. The mechanosensitivity of the capillaries was demonstrated when a positive micro-tactile physical stimulation was confirmed [12]. For further insight in vascular regulation and vasodilating substances [4,10].

2.2. The integrity of the endothelium

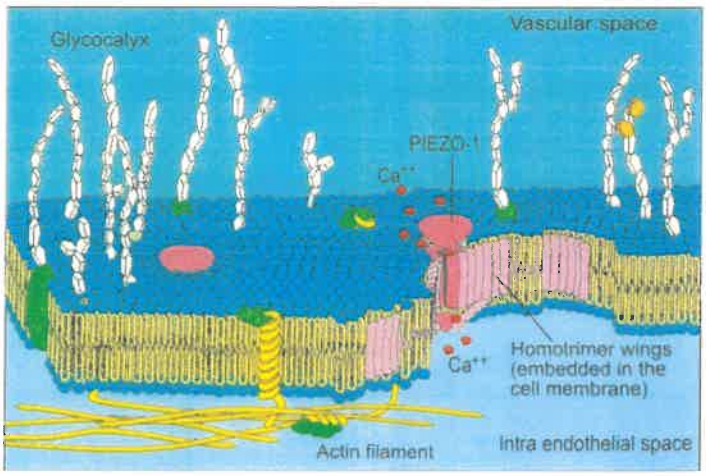


Fig 2 Schematic presentation of the endothelial semipermeable bio membrane with Glycocalyx and PIEZO-I channel, embedded in the endothelial cell membrane. One channel with a triggered Ca^{2+}-inflow. The actin ring (intra-endothelial) is indicated. The wings are moved by mechanical forces on the membrane and release the channel in an opening movement. Blue/Yellow: endothelial bio membrane with lipid bilayer structure [5]

The integrity of the endothelium is crucial for maintaining endothelial functions properly.

a) *Vasomotion*: A fine, non-pulsating vascular movement is extremely typical for a microcirculation with an *intact endothelium.* Even the smallest disturbances can cause *vasomotion* [13] to disappear. Due to its very low movement with sinusoidal changes of 0.1 Hz in the vessel, vasomotion *cannot* be easily observed in *SDF microscopy* [14]. Allowing precise measurements of vasodynamics, authors Zhang et al., 2024, introduced the method of *two-photon microscopy* [15]. As the authors note, vasomotion is crucial for e.g., brain homeostasis. In studies of cerebral blood flow in a mouse model, both native and after occlusion, they showed that vasomotion is of great importance in both the central and peripheral nervous systems. After stress caused by occlusion and reperfusion, vasomotion disappeared for a prolonged period. It was clarified that vasomotion also modulates fluid filtration pressure in the pulmonary vessels and that proper testicular function depends on intact vasomotion. It is expected that the benefits of intact vasomotion can also be demonstrated for the cardiovascular system and other vital systems.

b) *Glycocalyx:* The *glycocalyx* plays a special role in endothelial *integrity*. Only its base is firmly anchored in the endothelium. The part that extends into the bloodstream is subject to constant change, as it is in a continuous state of formation and degradation and at the same time acts as a sensitive mechano-sensor. Damage, known as *shedding*, has been shown to be caused by the effects of increased mechanical and oscillating stress as well as increased free oxygen radicals *(ROS*). In critically ill patients, the extent of *glycocalyx* damage correlates with their morbidity and mortality [2,16,17].

Loss of endothelial integrity:

Other factors that can lead to an oxidative stress syndrome (OSS) include elevated blood sugar levels, increased lipid peroxidation and stress factors, caused by vasoactive substances, e.g., the sympathetic nervous system or angiotensin axis. Elevated cortisol levels also lead to the formation of oxygen radicals (ROS), [5], cap. 8.2. page 54.

Why we must expect more than additive harmful effects with especially big wind turbines of current design is explained below:

The microplastic abrasion from today's wind turbines includes not only epoxy which is 40% Bisphenol-A (BPA), a frequently banned endocrine disruptor, but also per- and polyfluoroalkyl substances (also known as PFAS, PFASs, and sometimes referred to as 'forever chemicals`) [19]. One of the deleterious effects of *overproduced NO* is Increased susceptibility for radiation, alkylating substances and toxic metals, compare 2.4. TAB 1.

Loss of endothelial integrity: Early atherosclerotic lesions usually develop at vascular bifurcations and curvatures of large and medium-sized arteries, where laminar flow is disturbed and oscillating stresses are present [22]. In [7,18,20,21], the development from an intact endothelium into a state of inflammation, is presented. Endothelial dysfunction is both, a consequence *of* and a causal contributor *to* an altered metabolism in the endothelial cell. As a result, the endothelial communication with other cell populations such as macrophages, monocytes and also smooth muscle cells is disrupted, leading to vascular dysfunction and triggering a cascade of intra- and extracellular signals such as endothelial secreted mediators (*cytokines*) [23]. All these factors together lead to easier transport of lipoproteins in the subendothelial space and to the maintenance of chronic inflammation and an increased risk of thrombosis. In case of chronic circulatory disorders and proatherogenic stimuli, endothelial cells partially or completely undergo a transition to *mesenchymal* cells with corresponding properties. In addition, the pathological activation of PIEZO channels leads to expression of *various pro-inflammatory genes* and also serves as a critical mediator for an inflammatory response [18,24,25], At the same time, an intracellular increase in Ca^{2+} can be registered.

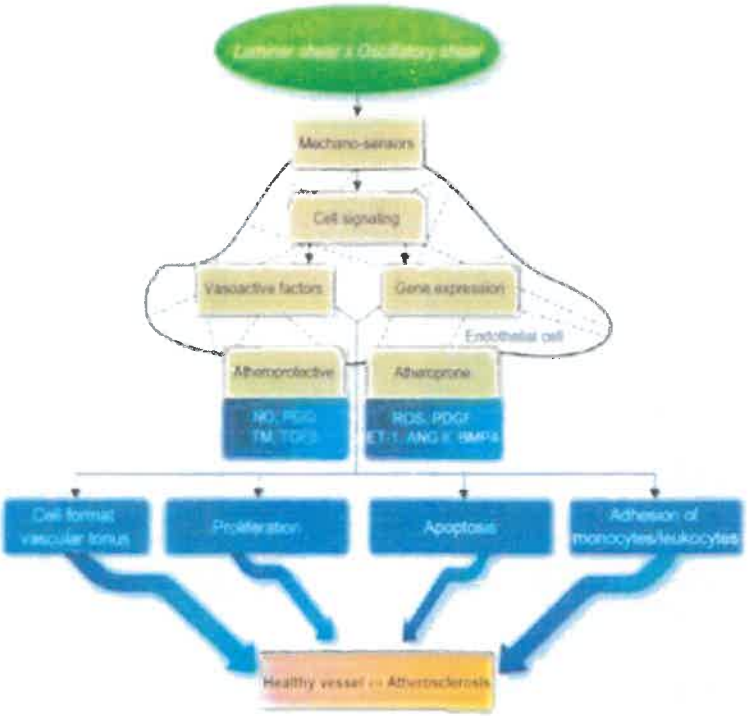


Figure 3 Original description [7]: Different effects of laminar and oscillatory shear on cell function and atherosclerosis. The *dotted lines* represent the endothelial cell cytoskeleton.

Laminar and oscillatory shear forces are recognized in endothelial cells by mechanosensors and the mechanosignals initiate signalling cascades that regulate the production of vasoactive factors and the balance between these factors. While laminar shear stimulates the production of atheroprotective factors, oscillatory shear stimulates the production of atherogenic factors and the balance of these factors determines the vessel tendency to stay healthy or to develop atherogenic plaques. PGI2, prostacyclin; TM, thrombomodulin; TGFb, Transforming Growth Factor beta; PDGF, Platelet-Derived Growth Factor; ET-1, Endothelin-1; BMP4, Bone Morphogenetic Protein 4. Adapted from Jo H, Song H, Mowbray A. Role of NADPH oxidases in disturbed flow- and BMP4-induced inflammation and atherosclerosis. Antioxid Redox Signal 2006; 8: 1609-19. Overview over the different effects of laminar and oscillatory shear stress on cell function and atherosclerosis. Original source [7]: *Fernandes CD, Araujo Thai's S, Laurindo FRM, Tanaka LY. Hemodynamic Forces in the Endothelium. Mechanotransduction to Implications on Development of Atherosclerosis. In: ENDOTHELIUM AND CARDIOVASCULAR DISEASES. Vascular Biology and Clinical Syndromes. Edited by PROTASIO L. DA LUZ.PETER LIBBY ANTONIO C. P. CHAGAS. FRANCISCO R. M. LAURINDO. Publisher: Mica Haley. Sao Paolo. (2018) ISBN 978-0-12-812348-5 Cap. 7 FIG 7.3, p 90.*8 With permission.

2.3. Redox System Homeostasis

NO is one of the most potent antioxidants and plays *a critical role in the homeostasis of overall redox metabolism by interrupting lipid peroxidation and thus reducing ROS* [1,23] (Tab 1]. In all organisms, NO freely diffuses through the membranes [3,5]. The vascular effects of *NO* are either presented *as vascular protective, regulatory or damaging* [1,23]. Various factors determine how the effect is realised. Protective effects have an appropriate *NO production* [1], but remarkably, *excessive NO production* is associated with *detrimental effects [1,23].* NO overproduction leads *to lipid peroxidation, depletes antioxidant stores* and *increases susceptibility to radiation, alkylating agents and toxic metals like already mentioned.* It also *inhibits enzyme function and causes DNA damage* (Table 1).

Table 1. The different possible effects of Nitric Oxide as protective, regulatory and deleterious

Protective effects:
• Antioxidant
• Inhibits leucocytes and platelets adhesion

- Protects against toxicity and peroxidation

Regulatory effects:

- Vascular tone
- Cell adhesion
- Vascular permeability
- Neurotransmission
- Bronchodilation
- Inflammation regulation
- Regulation renal function

Deleterious effects

- Inhibits enzymatic function
- Induces DNA damage
- Induces lipid peroxidation
- Increases susceptibility for radiation, alkylating substances, toxic metals
- Depletes reservations of antioxidants

After Original source [23] FIG 1 in WINK AA. MITCHELL J (1998) CHEMICAL BIOLOGY OF NITRIC OXIDE: INSIGHTS INTO REGULATORY, CYTOTOXIC, AND CYTOPROTECTIVE MECHANISMS OF NITRIC OXIDE, Radiation Biology Branch, National Cancer Institute, Bethesda, MD, USA from Book Free Radical Biology & Medicine, Vol. 25, Nos. 4/5, pp. 434-456, 1998. Published by Elsevier Science Inc. 0891-5849/98 $0.00 1.00 reference FIG 1 Page 435.

Crucial for both, a synchronised blood flow regulation and the maintenance of high *NO bioavailability,* is an *adequate release of NO in the right amount, the right place and at the right time.* This is only possible if the triggering forces result in demand-driven information. More details to the whole theme inclusive the involvement of endothelial NO- synthase isoenzymes in redox signalling pathways in orig. articles [1,22,23,26].

2.4. A `Tensegrity Structure` of the Endothelial Cytoskeleton offers the precondition for endothelial mechanotransduction

Named after Fuller [27], the structure combines structural stability, lightness and elasticity *for power transmission.* Actin filaments, microtubules and intermediate filaments as *intercommunicating networks*, take on the *elastic*, the *non-compressible* and *the connecting part*, respectively. Actin filaments serve to maintain the cell shape by forming a ring under the cell membrane [27,28] FIG. 2 which is connected to flow sensors (mechano-sensors) and membrane focal adhesion points (FAS*) – the 'anchor points in the tensegrity model' – as well as the intercellular gap junctions (CCAP)*. The original article [28] provide a more in-depth insight into this topic. In response to contractile stimuli, *actin and myosin filaments* form membrane-bound, parallel-organised units called '*stress fibres*', which stimulate myosin to slide along actin filaments. This leads to an increase in intracellular tension and thus cell contraction according to Wang [29] and Lee [30]. The closing and opening of paracellular gaps in response to inflammation, ischemia and invading substances (*gate-keeper-function*) is essential according to [31].

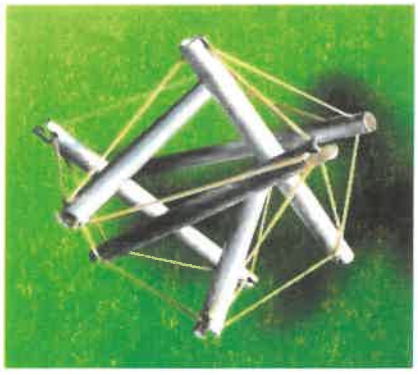


FIG 4: "Tensegrity" Model "in a schematic presentation [5].

Graphic Bellut-Staeck

2.5. Selected endothelial functions

2.5.1. Inflammation and Fibrosis Homeostasis

To maintain structure and function, an inflammatory response is essential as *a physiological defence mechanism* against, e.g., bacteria, viruses and injuries. All consecutive reactions depend on the *integrity of the endothelium* and involve the *endothelial cytoskeleton.* Since it is a *vital endothelial function*, the complex process of inflammation can be disrupted at any level, Suthahar [32]. Point of no return is the *diapedesis of leucocytes*. The further course leads in

the favourable case to a *restitutio ad integrum*, in the unfavourable to a *chronic inflammation* with fibrosis, defect healing and possible organ damage with loss of function. Important works on the state of the science come from Ley [33]and Serhan [34], related work in particular from Nussbaum and Sperando [35,36]. According to these authors, the orderly process in all phases is crucial for its outcome. At the centre of the process is the adequate *gate-keeper-function* of an *endothelium in an integrity state.* In order to *lead to a restitutio ad integrum*, the whole process is dependent on the *absence of increased oxidative and oscillatory stress*, in detail in [4,] in cap.2.4. In clinical medicine, shifts towards chronic inflammation play a major role.[12].

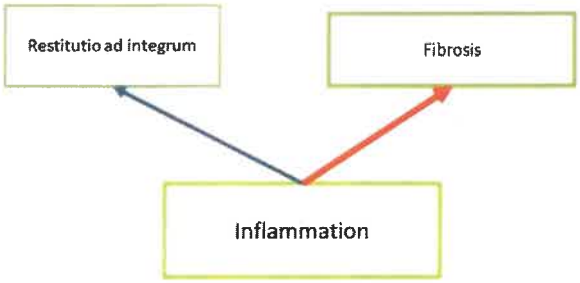


FIG 5: Schematic representation of the homeostasis of inflammation. Disturbance under chronic oscillatory and/or oxidative stress drives shift towards defect healing [5] Graphic 1.4 Bellut-Staeck

The standard works by Buckley [37]and Serhan [34] describe the sequences after the leukocyte diapedesis [5,38]. Failure of such regulatory mechanisms can likewise lead to a state of *chronic inflammation*, causing continuous tissue damage and progressive fibrosis. A classic example is the chronic heart failure by "remodelling" of heart, which can trigger a vicious circle [32, 5]. At heart, immunocompetent myofibroblasts and factors of the ECR actively modulate the development of initially perivascular and later progressive fibrosis. Starting points can be the development of myocarditis into a chronic form, state after myocardial infarction and/or *chronic mechanic pressure load on the he*art (systemic high pressure or pulmonary hypertension). The consequence is the increase in diffusion distance, the decrease in capillary density, an impaired electroconductive system with cardiac arrhythmia, disruption of angiogenesis, leading again to a deteriorated substrate and oxygen supply with a self-reinforcing process: *a vicious circle* [34]. According to the state of PIEZO research, the overstimulation of PIEZO channels can also contribute to this deterioration [24], cap 2.4.

2.5.2. Embryogenesis

According to the current state of knowledge, the importance of external forces, in particular repeated exposure to low frequencies and vibration during the pregnancy, must be classified as significantly more harmful than previously assumed. The high sensitivity is related to various stages particularly of embryonic development which are physiologically based on an undisturbed capillary flow. Examples of particular phases of increased sensitivity are e.g., the *vasculogenesis*. After differentiation of endothelial progenitor cells [4] and their fusion into a primary capillary plexus [31], the growth direction of the vascular tree is essentially regulated by shear *stress* of the blood stream and thus by mechanotransduction, Hahn and Schwartz [40]. PIEZO-I channels play a vital role here, without no embryogenesis would take place. Changes in shear stress pattern drive *immediate vasomotor* changes, which are regulated, as we know, on a '*beat-to-beat*' basis [19,38]. In this way, unexpected force driven disturbances can have *deleterious effects* [19]. Basing on some mutational *human PIEZO- gene* diseases such as the congenital *xerocystosis* or *congenital lymphatic dysplasia,* the erythrocytes and the lymphatic system is highly dependent on adequate forces. The last is characterised clinically by a lymphoedema. The network of lymphatic vessels with its own endothelium regulates the turgor and homeostasis of the interstitium and the lymphatic valve formation by shear forces. In consequence also there is a high sensitivity for an impact with external forces [41].

The neural development process is comparably sensitive to mechanical properties of its environment. One aspect is the alignment of neural stem cells into different *phenotypes* [24] and cap. *3.4. The important role* of Piezo-I in endothelial morphogenesis with dependent endothelial functions, suggests that damaging external forces must be strictly avoided during pregnancy.

In the dissertation "*Acquired flexural deformation of the distal interphalangeal joint in foals*" the influence of deep frequencies and vibration on embryogenesis becomes apparent. With the commissioning of three IWT`s at distances of 350 to 800 meters from the farm in 2008, an increased incidence of flexural deformities – especially 11 individuals affected- was observed, also abnormalities in other tissues were found. Histologically, the most significant alterations were the dissociation of myofibrils of the smooth muscle cells. This was predominantly seen in the small intestine but also in the walls of small capillary vessels, including those of the tendon vasculature [32}.

The chapter PIEZO channels in cap. 3.4. presents current results of PIEZO research on the occurrence and function of PIEZO channels in various organs. This may only be a small part

of what influences embryonic development and how is its sensitivity to external and internal forces.

2.5.3. Homeostasis coagulation

Healthy endothelium plays an important anticoagulatory and antithrombotic role. Further insight is provided by ANNICHINO-BIZZACCHI und VINICIUS DE PAULA (2018) [43] in cap. 11, S. 148 and [4] in cap. 4.3.

3 Mechanotransduction

The conversion of mechanical forces into biological information, which is increasingly emerging *as a comprehensive mechanism for all living* things, is represented by the conductivity of biological structures, the presence of mechano-sensors, the conversion process from a physical into a chemical or electrical signal as information and the induced biological and/or biochemical response.

3.1. Hemodynamic Forces

Physiologically, physical forces constantly act on the organism, e.g., *gravidity, pressure, proprioception, shear stress* and *vibration*. The major ones come from the blood flow itself and are tangential forces e.g., *laminar shear stress* or stretching forces e.g., *pulsatile distention* according to Fernandes et al. [19] and Mazzag et al. [44] As described above, *internal oscillatory stressors are physiologically limited in the capillary bed by the vessel size* [1]. As a result, we find *physiologically laminar flow* in the capillary bed. [1,2,19].

3.2. Mechanical Force Transmission via "Biophysical" Pathway"

The observation that many processes take place very much faster than the *mechano-chemical* pathway via *gene expression* and *protein synthesis* would allow – protein synthesis needs a minimum of some seconds – led to intensive research in the "tensegrity" structure of the cytoskeleton and to the definition of the "*biophysical pathway*" [1,44]. *In the example of endothelial mechanotransduction*, this pathway relies on direct physical links between *specific mechano-sensors of* the endothelial surface and the endothelial cytoskeleton. It allows cells to transfer mechanical stimuli over long distances and very importantly, in a "*spatially heterogenic excitation ", quote Mazzag* [44]. Crucial work with important relevance to our work is the research on the dynamics and distribution of transmission in response to "*noisy flow*" from Mazzag and Gouget in [44] and Mazzag and Barakat. in [45]. By "noisy" flow, the authors mean an "*oscillating or turbulent flow* under *conditions with random fluctuations in*

the flow properties of pressure and velocity", quote Mazzag, Barakat 2010 on page 912 [45]. To the predecessors in the exploration compare [38]. To better understand the dynamics of force transmission via cytoskeletal filaments, several *mathematical models* have been developed. The authors Mazzag and Barakat present an overview with possibilities and limitations in [45].

The "Temporal Network Model 2, as presented in [44] and [45] is based on a *viscoelastic structure* of a *tensegrity model (*FIG 4). The results show that the amplitude of the *oscillations* in the 'noisy' flow is *more strongly answered than its duration, which could be an explanation for why an 'impulse force' is answered more strongly than a constant.*" [45]. A summarising evaluation is provided in Mazzag [44] with further developments of models, e.g., such as the "*spatio-temporal network model*". Important quote on this topic on page 101[44]: *"At sufficiently low oscillatory frequencies, the peak deformations match those for constant forcing; however, above a threshold frequency, the peak deformations drop significantly. The analysis demonstrated that this threshold frequency is in the range of* 10^{-5} - 10^{-4} *Hz for microtubules and* 10^{-3}- 10^{-2} *Hz for actin stress fibres, suggesting that stress fibres can effectively transmit force over a wider frequency range.*"

Na *et al.* [46] confirmed in an experimental study the transfer speeds and effects, predicted by the computer model. The experiment *used infrasound* as physical force. It could be demonstrated, that the *biophysical way* is about 40 times faster–*namely 300 milliseconds*– than the route by pathway of gene expression.

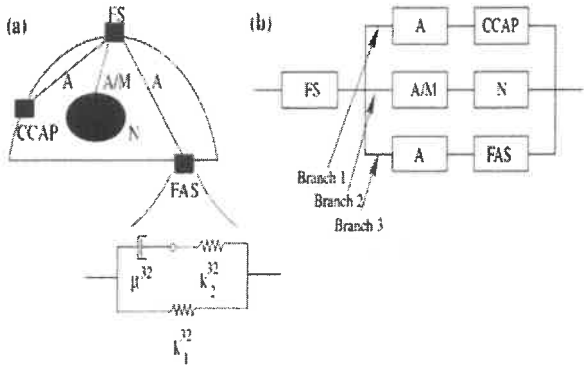


FIG 6. Original description [44,45]: Schematic representation of an EC consisting of a mechano-sensor (MS), cytoskeletal elements (either actin stress fibres (a) or microtubules (M)), a nucleus (N), cell-cell adhesion proteins (CCAP), and focal adhesion site (FAS). The inset shows a TPMM (or Kelvin body) representation and the viscoelastic parameters for

FAS. The superscripts '32' on the parameters indicate that this element is the second element on the third branch (see text). (b) Branching network representation of the EC components in panel A. Each cell component corresponds to a TPMM, coupled to other components according to the diagram shown. Actin stress fibre and CCAP connected in series are referred to as Branch 1, actin stress fibre/microtubule in series with the nucleus is Branch 2, and actin stress fibre in series with the FAS is Branch 3. (a) Schematic representation of an endothelial cell consisting of a flow-sensor (FS), cytoskeletal elements actin filament (a) or microtubules (b) and the connections (N), (CCAP), (FAS). (b) Mathematical representation. Original source [44,45]: Temporal Network Model FIG 1 *Bori Mazzag, Cecile L. M. Gouget, Yongyun Hwang* and *Abdul I. Barakat* (2014) [44] Cap. 5. Page 98 [45] Mechanical Force Transmission via the Cytoskeleton in Vascular Endothelial Cells. In Endothelial Cytoskeleton. *Editors* Juan A. Rosado and Pedro C. Redondo Department of Physiology, University of Extremadura Cáceres, Spain. With permission

3.3. The Mechano-Sensors of the Endothelial Cell

The endothelial *mechanotransduction* occurs *directly*, without delay, as shown in chapter 3.2.

On the side facing the vessel (luminal), mechano-sensors are especially *the cytoskeleton itself* [19], the *glycocalyx*, *integrins*, *cell-cell junctions* (*CCAP*), *caveolae*, *lipid rafts*, *G-protein coupled receptors and PIEZO-I-channels (*designated as ion channels as of 2019, FIG 4 in [1]. They are activated according to their location via shear stress [1,48]. Endothelial mechano-sensors are altered in their microenvironment by shear stress and can activate intracellular signalling pathways in this new formation. The fluidity of microdomains in the plasma membrane is altered after [1]. This leads to a spatial rearrangement of various proteins and thus to the activation of signalling pathways. The *transmission of forces* takes place via the three intercommunicating networks to the basal region of the cytoskeleton (e.g., Integrins) [1,44,45]. One of the most important mechano-sensors is the *glycocalyx* ([1,2]. In critically ill patients, the extent of the *glycocalyx* damage –so called *shedding*– correlates with the severity of disease and mortality [2,21,47].

3.4. A closer look to a special mechano-sensor: the PIEZO-channels

Ardem Patapoutian was awarded 2021 the Nobel prize in Medicine for establishing PIEZO channels *as a sensory system of internal organs via receptors for pressure and vibration in all vessels and the skin,* David Julius was awarded for TRPV1- channels as receptors for heat and cold. *"TRPV1 and PIEZO channels provide a completely new basis for sensing mechanical forces and vibration, heat and cold." Quote page 1 [48]. [...] "The work by the two laureates*

has unlocked one of the secrets of nature by explaining the molecular basis for sensing heat, cold and mechanical force, which is fundamental for our ability to feel, interpret and interact with our internal and external environment."

PIEZO ion channels in general mediate the *conversion of mechanical forces into electrical signals* and are conserved structures in *all* multicellular organisms, also plants, therefore important for all living entities from plants, bacteria up to mammals. In line with their significance, they are *in the focus of actual PIEZO research.*

PIEZO proteins form *homotrimer structures* with a central ion-conducting pore and three peripheral large mechano-sensitive propeller-shaped wings. See schematic graphic in FIG 7. *When Ca^{2+} permeable PIEZO-I* channels are activated by physical force on the cell membrane, they flatten the wings in an opening movement and reveal the entrance to a central pore, using a *unique lever mechanism* [24]. The Na^{2+}/Ca^{2+} channel is activated and triggers a signal transduction via a Ca^{2+} influx, Rode et al. 2017 [49], therefore *PIEZO-I is responsible for flow-sensitive, non-inactivating, non-selective cationic channels which depolarize the membrane potential.* In a remarkable research progress, authors like Fang [24] characterized PIEZO- I and- II channels in their protein structure, biological functionality and their possibly biophysical significance and used new techniques such as the *cryo-electron-microscopy*, comparative studies with a mouse model (*mPIEZO*) and e.g., the comparison with known PIEZO channel gene mutations. These are for example the autosomal dominant xerocystosis, the autosomal recessive congenital lymphatic dysplasia, the autosomal recessive syndrome of muscular atrophy with perinatal respiratory distress. In FIG 7 there is a schematic presentation of a PIEZO-I channel in an A closed and B open position.

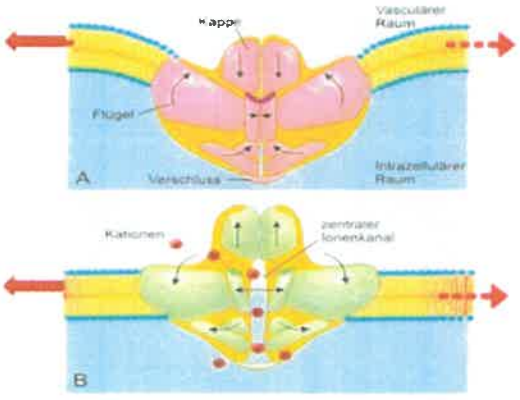


FIG 7 Schematic representation of a PIEZO I channel in a closed A and B open position. Graphic Bellut-Staeck

In eukaryotic cells, a plurality of ion channels is involved in *mechanotransduction* pathways. An overview is given in [24] in Tab. 9. Some do not occur as conserved structures in mammals, but in invertebrates. Some of them, *transient receptor potential channels in particular (TRP)* are not only sensible to forces, but also to chemicals, temperature, osmolarity and heat [24]. Quote page 1 [24]: "*Furthermore, most MS candidates, the TRP channel in particular, are activated not only by mechanical stimuli by but also by chemicals, temperature, osmolarity, and heat (> 27–34 °C).*" An additional voltage dependence is described from Sachs, Gottlieb and Moroni [50,51].

3.4.1. Expression of PIEZO- I and -II in multiple tissues

As a result of actual PIEZO-channel research, the following body regions and organs are apparently particularly characterized by *mechanotransduction processes* via PIEZO-I channels such as the *cardiovascular system*, the neuronal *development*, the gastrointestinal *tract*, the lung *endothelium* and the *urinary tract,* (FIG 8). PIEZO-II channels dominate in the somatosensory via Dorsal Root Ganglion, articular cartilage, balance, proprioception and pain. [24]. FIG 8 demonstrates an overview of the occurrence of PIEZO-I channels and II channels in different organs.

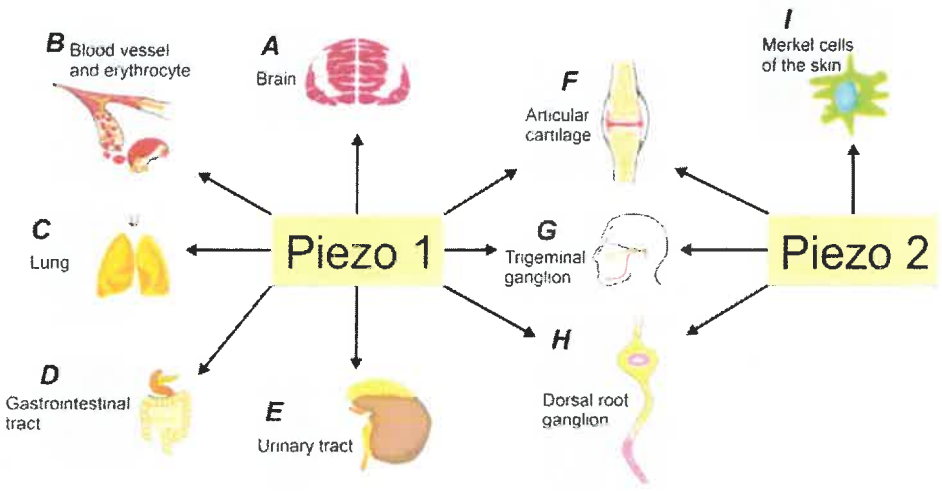


FIG. 8 After Fang[+] et al. [24] Schematic overview: Expression and function of Piezo channels Multiple tissues and cells express Piezo channels. a–e demonstrates the vital role of the Piezo1 channel in the CNS, blood vessels, erythrocytes, lungs, gastrointestinal tract and urinary tract. f–h illustrates the expression of both the Piezo1 channel and Piezo2 channel in articular cartilage, trigeminal ganglia, and dorsal root ganglia. i shows that the Piezo2 channel is expressed in Merkel cells, which are involved in sensing light touch

The *cardiovascular system*: The regulation *of vascular tone, blood pressure and adequate provision of NO,* takes place in the classical *laminar shear stress reaction.* The PIEZO-I channel is activated and releases adenosine triphosphate (*ATP).* The phosphorylation of endothelial *NO-synthetase* leads to NO-production and adequate vasodilation [24,38]. PIEZO-I channels also play an important role in erythrocyte homeostasis in regulating its volume and plasticity [24]. Erythrocytes themselves release *ATP* via own PIEZO-I channels. Different manifestations of the dominant hereditary disease *xerocystosis* are incompatible with life. PIEZO-I senses whole body's physical activity to reset *cardiovascular homeostasis* and enhance performance by a *dichotomic* reaction of the endothelial cell in the mesenteric tract as answer to physical stress [49,5].

A new aspect in Fang's work is the involvement of PIEZO channels in the *baroreceptor reflex. B*oth PIEZO -I and -II channels are highly expressed in the *nodose-petrosal-jugular-ganglion complex.* Physiologically a *beat-to-beat* regulation of the blood pressure takes place. According to Fang, the knockout of both PIEZO-I and -II channels led to a fully impairment of the baroreceptor reflex [24], FIG 8. Hailin Liu et al. (2022) [52] confirm the correlation between uncontrolled overstimulation of PIEZO-I channels, usually in connection with increased tissue pressure and the development from an acute to a chronic inflammation situation. This applies, for example, to *cardiac fibrosis. In a feedback loop*, myocardial fibrosis leads to *increased atrial pressure* and *overstretching of the heart muscle* via stimulation of PIEZO-I, which in turn leads to increased Ca^{2+} -influx, *promotion of inflammation* and *proliferation of fibroblasts* with increasing fibrosis.

PIEZO- I and its role *in the endothelium of lung*: Due to an increased hydrostatic and alveolar pressure, the lung endothelium as well as alveolar cells are physiologically and artificially – in mechanical ventilation— exposed to an increased mechanical stress. There is a high expression with PIEZO-I channels in the lung´s endothelium. Proven is that mechanical stress like a mechanical ventilation is activating PIEZO-*I* and leading to an increased Ca^{2+} influx that subsequently is followed by an *apoptosis* of the alveolar cell. Conversely, mechanical stimulation of Piezo-I channels in alveolar type I cells triggers *ATP* release and paracrine stimulation of surfactant secretion that maintain lung function. According to [52], in chronic lung diseases, the increase in tissue pressure causes positive feedback on PIEZO-I channels, which exacerbates the process via pro-inflammatory pathways and via fibrosis. According to these authors, overstimulation of PIEZO-I channels which is leading to excessive surfactant formation, also tends to have negative effects on the outcome.

Organ systems with a high number of PIEZO channels outside the cardiovascular system and lung:

The PIEZO- I channel and its role *in **nervous system***: The discovery of PIEZO-I channels in structures of the *central nervous system (CNS)* led to research in their biophysical functions. According to Fang, the result is the transmission of mechanical forces from the environment of *the extracellular matrix (ECM)* into information that results in many processes such as cell *division, migration, morphogenesis, vesicular transport, gene expression and fluid homeostasis*. In *CNS* PIEZO-I was detected in myelinated axonal pathways (more than in demyelinated) of the mouse brain, including *corpus callosum and cerebellar* arbor vitae [24]. PIEZO channels apparently play an important role in the *neuronal development* such as the differentiation of neural stem cells into *neurons, astrocytes **or** oligodendrocytes*. Here a particular sensitivity to external forces is described. Ca^{2+}-influx, following triggered PIEZO-channels, directed the choice of neuronal stem cell towards a *neuronal phenotype*, while inhibition or knockdown of Piezo1 suppressed *neurogenesis* and enhanced *astrogenesis,* Quote Fang [24] page 12: "[...]" "*Is the Piezo1 channel also involved in astrocyte-neuron interactions that are key for the maintenance and regulation of neuronal function? An elegant study by Blumenthal et al. showed that pharmacological inhibition of Piezo1 abolished neuronal sensitivity to nanoroughness, a mechanical signal resulting from neighbouring cells and ECM molecules, and sequentially promoted the decoupling of neurons from astrocytes, thus providing evidence for the role of Piezo1 in neuron–astrocyte interactions. This information provides a clue for answering this question.*" According Liu et al., local increase of stiffness in the brain with a high mechanical sensivity of neurons and astrocytes, can lead in a positive loop to *further stiffness*. Connections with Alzheimer's disease are under discussion. Deeper insight in the original article.

PIEZO-I and –II channels in the ***gastrointestinal (GI) tract*:** According to Fang, chromaffin epithelial cells are enriched in humans and e.g., mouse GI tract and produce serotonin in response to mechanical forces within milliseconds. In the submucosa, multifunctional mechano-sensors in enteric neurons have been identified. The function of the PIEZO channels, found in enteric neurons of humans and mice still needs to be investigated in more detail in [24].

PIEZO-channels in *the **urinary tract***: According to Fang, piezo-I channels are expressed in the overall urinary tract, including epithelial cells, interstitial cells, and smooth and striated

muscle cells. The ability to sense intraluminal pressure and changes in the flow, is a crucial precondition for a proper function. A deeper insight in the original article [24].

In the cartilage, PIEZO -I and-II are apparently partly responsible for the inflammatory processes caused by increased pressure, for example as a result of osteoarthritis.

3.4.2. Mechanotransduction in plants

To demonstrate the extraordinary important role of mechanotransduction, here a chapter to plants. Like animals, plants are *living organisms* with life cycles and vital reactions to environmental stressors. In plants we find corresponding structures such as a *cytoskeleton, mechano-sensors* and *mechanotransduction pathways*. Plants, along with animals and fungi, have a cell nucleus as eukaryotes, unlike prokaryotes. A rigid cell wall surrounds the living cell substance (protoplast) with the cytoplasm and the cell nucleus. We can find structures comparable to those of animals, such as *organelles, mitochondria, endoplasmic reticulum* and *Golgi apparatus, ribosomes, actin filaments and microtubules.* [53}. The difference in plants are especially the *plasmids*, sites of *photosynthesis* and the *vacuoles*. Comparable to animals are the structure and function elements from the six basic components elements H, C, O, N, Ph, S. Correspondingly to animals, four different molecules (glucose, proteins, lipids and phospholipids) and their compositions are the main components. In plants, energy is released by hydrolysis, energy (same amount) is introduced by condensation mechanisms. Similar to animals, *actin filaments* form a complex network with *intermediary filaments* and *microtubules* in the *cytoplasm* [54}. According to [54], plants are „prestressed structures" from shape-derived stress. Due to this fact, it is more difficult to recognize the functional processes in mechanosensory perception in plants. The intrinsic and external mechanical stress cannot be differentiated so easily. The epidermis of plant aerial organs is under *tension*, while inner tissues are under *compression.* As in animals, the *cytoskeleton* is also a central principle of the plant cell's response to mechanical stress. A*ctin* seems to orient along maximal tensile stress; internal turgor pressure is the engine for the growth. The most famous genes are called the TOUCH (TCH) genes, being induced within minutes after touch [54].

About 20 different mechanosensitive channels are described in plants.

An overview to different mechano-sensors in living things is given in FIG 9.

-

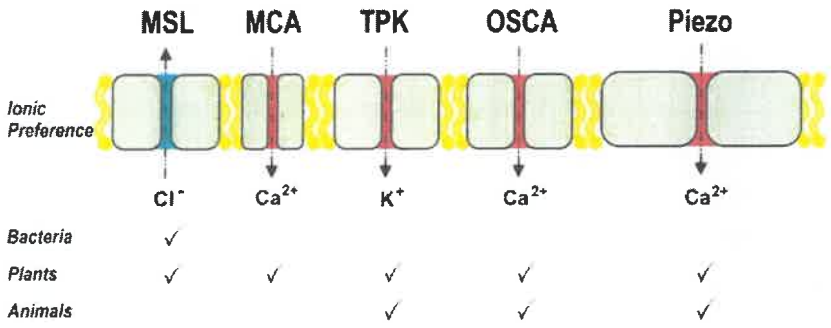


FIG. 9 Overview of different mechano-sensors after [54]. The presence of homologs in bacterial, plant, and/or animal genomes is indicated with a checkmark. The predominant ion flux is shown for each channel, but for simplicity no directionality nor specificity is shown. Shortened original description

Similar to the animal kingdom, mechanosensitive ion channels in plants are opened by lateral membrane tension and Ca^{2+}-Influx in context with mechanical stimuli. The perception of pollen tube growth, hypo- or hyperosmotic stress, gravity, vibration and touch or pathogenic invasion, is assigned to the function of mechanosensitive ion channels. Drought stress increases osmolarity. A trichome is an example for the trigger hair of a *Venus flytrap*. Its deformation leads to an increase in *apoplastic* (outside cytoplasma) pH and cytosolic Ca2+ oscillations in the cells [54]. When plants are under environmental *abiotic or biotic* stress, they reduce growth not only passively, but also actively as defence. This is achieved through stress-triggered cell signalling [55]. When there is an excess of light energy, the electron transfer in photosynthesis is significantly reduced, as a stress response. Similar to the reaction in the animal world, stress *leads to increased oxidative stress* (*ROS*), H_2 0_2 and other oxygen radicals and impairs the functions of the plant [55].

Plants respond to stress. They can release fleeting chemicals to protect themselves and also others from herbivores, e.g., so called VOC`s [56], but plants can also *"cry"*. The authors [56], 2023 examined the communication of plants with their outside world via *airborne ultrasound* that could be measured and recorded in a distance of 3-5 meters. This in turn requires a kind of "hearing ability". Plants can demonstrably respond to sound, inter alia, with a change in expressing specific genes. By training machine learning models, it was even possible to differ the emitted sound in its significance and thus to assign to *drought stress or injury*. Other organisms such as moths, are able to hear ultrasound, in this way could possibly communicate, also other plants. More insight in the theme bioacoustics and limitations of the study [23].

A study conducted between 2000 and 2022 on the reduction of *plant biomass production* (PBP) within a 10 km radius of each individual wind turbine shows that infrasound could be a significant stress factor for the entire environment. The study bases on an evaluation of 2404 wind farms with 108,361 turbines and shows significant consequences for the impact on plant growth [57]. The study analysed 10 PBP indicators such as the normalized differential vegetation index (NDVI), enhanced vegetation index (EVI), percentage of tree cover (PTC), percentage of non-tree vegetation cover (PNTV) and percentage of non-vegetation cover. A buffer zone of 10 kilometers was examined. The results show a significant negative impact on PBP, even if the extent of this impact varies depending on the indicator, respectively. The greatest negative impact can be observed in the summer and fall months and in relation to landscapes that are more flat than hilly. Furthermore, the negative impact increased for three years and persisted. The greatest negative effect e.g., *EVI* could be found between one and seven km with a maximum in 2 kilometers. An Example: "*The negative impact of wind farms on EVI is significant within 1 km to 8 km, with a peak at 2 km and a maximum decrease of − 0.0088 (P < 0.001; 95% CI − 0.0128 to − 0.0047)*". Quote in results [57] The authors consider the negative impacts on biodiversity to be *considerable*.

4. Noise and Sound

Pressure is force acting on a surface (N/ m^2) and measured in Pascal (Pa). Power per m^2(watts) is the *power density*. Sound, infrasound and ultrasound propagate as longitudinal waves in *all viscoelastic materials*, i.e., the pressure changes oscillate in the direction of propagation. It is an *energy transfer*. *Audible sound* is in the range from about *20 hertz (Hz) to 20 kilohertz (kHz), infrasound* is below 20 Hz and *ultrasound* above *20 kHz. Sound* differs physically in frequency and thus in wavelength. The wavelength (L) is in relation to the frequency (f) and to the speed of sound (V) in the respective medium. In general: The lower the frequency, the greater the wavelength, the lower the damping, the greater the flexural capacity of the sound. For example, sound propagation in air with a wave length of 0,1 Hz is about 3,4 km, that of 1000 Hz is about 34 mm. *Infrasound* is much less attenuated by propagation through the atmosphere as well as through roofs and walls than the *audio spectrum*. It propagates in all viscoelastic mediums, therefore also organisms. *Infrasound* is generated by heavily moving masses as well as by *resonance phenomena and vibrations*. Its exposure can be *occupational such as from the aviation industry or residential* such as from heat pumps, combined heat and power plants and as increasing factor from industrial wind turbines (IWT`*s*). *It* can be emitted

from *natural* (e.g., earthquakes) or *technical sources* (cars, airplanes) or residential emitters. The sound differs in frequency, sound pressure, time/effect profile (impulsiveness) and duration, which is crucial for *the information* it has and the organism's ability to *compensate and to recover*.

4.1. Properties of infrasound emissions from IWT`s

IWT`s are a particularly far-reaching environmental factor [58]. Every time a rotor blade passes the tower, air masses of high-pressure differences are emitted, which propagate as *infrasound*. These pulses lead to several integer multiples of the determined fundamental frequency, the so-called ´harmonics´. Harmonics occur with any waveform that *deviates* from a sinusoidal wave. Since infrasound does not propagate linearly from the source, higher values can often be measured at greater distances than near the source due to reflections [59]. Due to the increasing number and size of IWTs, complaints from local residents are therefore on the rise, especially after the so-called repowering (the replacement of an IWT with a greater one) [60]. The reason is suspected of being in the increasingly lower frequency due to the increasing length of the rotor. The larger the rotor, the lower the emitted frequency. Infrasound of IWT's is meanwhile with big parts in the range of 0.2 to 8 Hz according to the authors in [61,62,63]. The infrasound emissions are impulsive in the effect/time profile according to Roos, Vahl [62] and Vanderkooy [63], as shown in FIG 10. This is an important factor for the relevance of information when comparing reactions to impulsive signals or consistent signals [44.45].

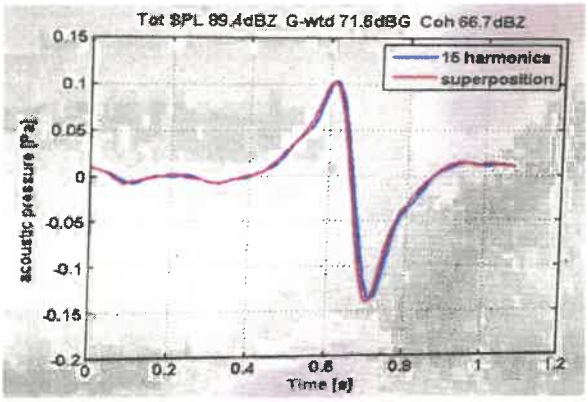


Figure 10 [63]: An infrasonic pulse extracted from the emission of a wind turbine. The fluctuations of sound pressure measurable near a wind installation usually contain noise, *i.e.*, irregular sound events of different origin. Noise removal is possible by averaging the sound pressure over a large number of mast-blade passages (here 4100), which reveals their common element (red line). The red peak thus visualized from the time sequence coincides

with the blue peak, which shows the fundamental pulse as reconstituted in the frequency domain from 15 (very sharp) harmonic lines by Fourier analysis. The result is the coherent fundamental peak of this turbine of 0.9 Hz frequency, accordant to 1.08 seconds required per blade passage. The extracted infrasonic pulse of a wind turbine shows the relation between sound pressure (P) and time (s). Original source [63]. corresponding to Figure 7 in Vanderkooy[1] J, Mann[2], R Measuring Wind Turbine Coherent Infrasound Department of Physics and Astronomy 1, Department of Computer Science 2 University of Waterloo, Waterloo, ON, Canada, N2L3G1 jv@uwaterloo.ca, mannr@uwaterloo.ca Date posted: 2 October, 2014. With permission.

Particularly in indoor spaces of buildings, interferences of airborne sound pressure and *structure-borne sound are possible*, which can lead also to relevant amplifications or attenuations of the total impacting sound [64]. The recording of the measured values must be done with suitable sound pressure levels [SPL], unweighted as shown in FIG 11.

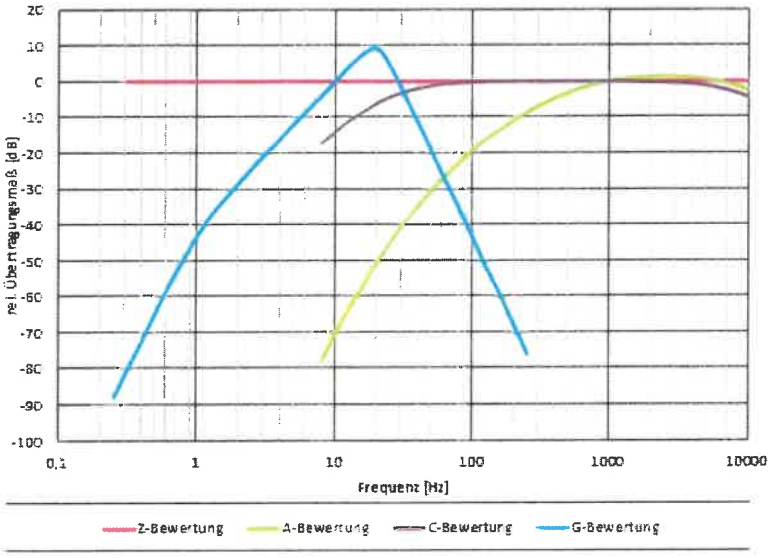


FIG 11: Typical frequency weighting curves in dBA, dBC, dBG and dBZ. Original source: Eulitz C., Zobel P., Ost L., Möhler U., Schröder M. (2020) Ermittlung und Bewertung tieffrequenter Geräusche in der Umgebung von Wohnbebauung, TEXTE 134/2020 [65]

As result in FIG 11 only the unweighted curve dBZ (red), can actually images infrasound. The G rating extends far into the infrasonic range, but with a significant loss of real sound pressure values.

The A- rating, which is suitable for evaluating audible sound, and the C- rating only extend to just below 10 Hz. The difference between the A- and C- ratings when more than 20 dB, can only indicate the presence of infrasound, not assess it.

The spectrum in FIG 12 shows that the main frequencies emissions from a IWT are below 8 Hz.

Remarks: According to the UBA (Environmental Protection Agency), the frequencies in the 30 Hz range cannot originate from the rotor blades, as the frequency difference is significantly different. It is assumed that these frequencies originate from the gearbox present in this wind turbine.

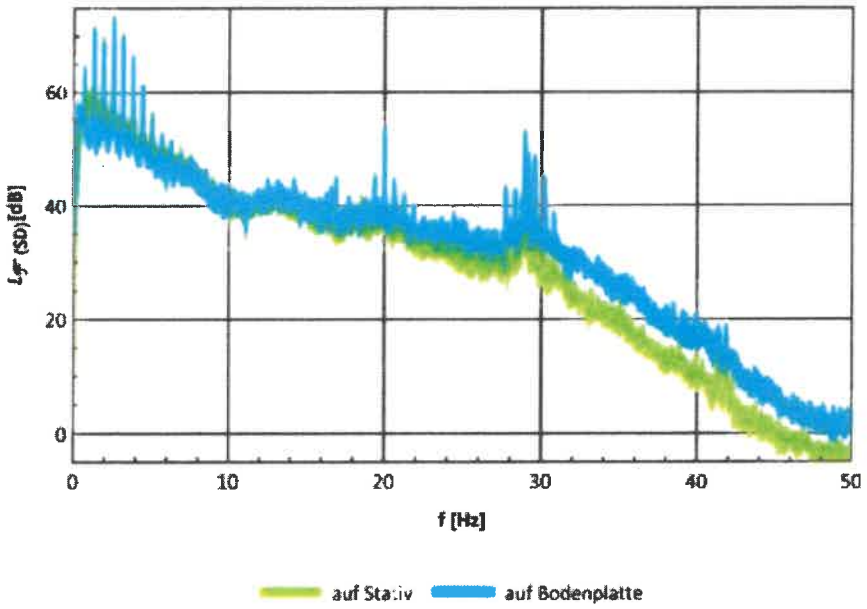


FIG 12: The following spectra are taken from: Texte 70/2022 (in English) Final Report, Federal Environment Agency, UBA Image 39: [66] Page 73

4.2. Information of an infrasound signal arises from all its qualities

Every cell interacts with its environment by exchanging *tiny quanta of energy* [59]. According to Persinger [59], it has been known for some time that living organisms vibrate in a range of mainly 6-12 Hz with amplitudes of 1-5 µm, and about 50 µm when muscles are tensed, and thus emit *sound* as a result of the fusion of all activated muscular subunits. During sleep, the amplitudes are reduced. In addition to natural sources, the environment is increasingly confronted with human-made sound waves in different frequencies, also increasing *infrasound.* At the current heights of the IWT`s above 250 meters and high rotation

speed, the emitted frequencies are in a similar range to one's own body vibrations. It is known that resonances, which arise in spatial and temporal similar patterns, can lead to a significant instability of the *overall system* even with minimal stimuli.

Quote Persinger [59] page 503: "*Pure sine waves or simple time-varying patterns are found less frequently in the environment than complex acoustic and electromagnetic patterns that have the potential to mediate information between the environment and cells at very low levels of intensities. Relying on only the average intensity overtime for these sources (such as infrasound) as indicators of their importance is about as useful as only measuring the loudness of a conversation to discern its syntactic content and meaningfulness* ". Thereby the effects of impact do not require awareness [83].

Black box IWT: IWT`s with heights of 250m+ reach meanwhile verifiable a ground frequency of about 0,25 Hz. The frequency between 0,2 and 4 Hz corresponds to the slow delta waves of the brain during sleep; this could disrupt the synchronized *release of hormones and proteins* involved in repair mechanisms and disturb the homeostasis [59] inclusive the production of *serotonin* and *noradrenaline* of the brain stem. This could mean greater sensitivity during night-time sleep. According to Persinger frequencies below 10 Hz have *a high biological significance*.

Music also consists of a fundamental tone, which is overlaid with other tones in integer multiples of the fundamental frequency. As with music, the totality of information is not determined by a single characteristic, but by the interaction of all characteristics. These tones are called overtones or harmonics. Music can activate neural circuits that reach specific areas for emotions and reward. This leads to an instant improvement of the microcirculation [71,4]. An example according to Persinger of the variability of an information content: under slightly different circumstances, mundane stimuli can lead to a "disaster". According to Persinger, Murugan et al. (2013) [67] demonstrated that planarians - a type of aquatic flatworm- exposed to a specific field pattern of sound for a few hours per day, dissolved within two hours. The decisive factor was the effect over time. They dissolved when a different temporally structured field was applied on day five, but not after the first day.

4.3. Hydroacoustic

In the sea, sound propagates at 1480 m/s, which is about 4.3 times faster than in air. The pressure increases with depth; therefore, the speed of sound increases with the depth. However, it also increases with salinity and temperature. In the low-frequency range, water sound waves can be perceived over any uninterrupted stretch of water on earth. In an infinite

space at a constant speed of sound, sound intensity decreases with the square of the distance ($1/r^2$) and sound pressure decreases with the linear distance ($1/r$). According to Lurton,[68] in the northern hemisphere, the background noise below the surface of the sea is now permanently characterized by a diffuse noise from ships in frequencies between 100 and 300 Hz. More insight in the complex thematic, measured quantities and reference levels in the original article.

The authors [68] examined acoustic differences between deep and *shallow waters*, which is important in regard to the location of offshore turbines (verifiable *offshore installations are anchored in the ground, from about 21 meters water depth up to about 120 meters water depth)*. It is important to note that only sound sources between *50 Hz and 50 KHz* - not the infrasound range- *were included in this study*. Quote in Chapter 6 in Katsnelson B, Petnikov [69]*: „An extremely important part of shallow water acoustics is the study of long-range, low-frequency reverberation. In particular, one is studying acoustic wave backscattering by medium inhomogeneities, which are generally separated by a distance of a few to several tens of kilometres from a sound source and receiver. [...] This reverberation, along with its main role as an undesired noise signal, can also play the role of an additional source of environmental information* ". When infrasonic sound waves are continuously emitted from *offshore wind turbines*, they will be likewise carried continuously to the next land mass in a constant repetition. So far, no studies have been conducted that look at the effects of inaudible noise in deep frequencies *on marine ecosystems*. The special hydroacoustic properties not only threaten the orientation of whales and their communication, but also their *vital functions.*

5. The Hypothesis

5.1 The paradigm shift

Effect and conscious perception must be considered completely independently of each other. [24,59,83]**.** The biological significance of information depends on *numerous factors*. All cells exchange information and oscillate. All organisms have a crucial level of perception via mechano-sensors. Mechanotransduction is one of the essential foundations for *maintaining structure, function and communication.* For this reason, external forces are able to cause a disruption of vital functions due to certain properties.

5.2. The Hypothesis in Detail

- Noise, when it affects organisms, is under *certain conditions in frequency, sound pressure, effect/time profile and duration* able, to lead to irregular information's on the mechano-sensor level.
- The consequences of irregular information's at the endothelial mechano-sensor level of the PIEZO channels are e.g., an inadequate NO release with an increase in oxidative and oscillatory stress as well as a lack of energy due to a disruption of the autochthonous vascular regulation.

In chronic impact this will lead to a loss of endothelial integrity with all consequences.

- With decreasing frequency, there is an increasing transmission of irregular information. This means increasing harm with decreasing frequency.
- Functional and later on structural disorders are particularly conceivable in all organ systems.
- Plants have comparable mechanisms and can therefore also be affected in essential functions by irregular information.
- Once the homeostasis of tissue pressure is disturbed in various organs, there is an additional risk of aggravation and self-reinforcement due to overstimulation of PIEZO channels everywhere they are located.
- The possible consequences might be severe, In particular for embryological, cardiovascular and neurological functions.

5.3. The Hypothesis Is based on the Evidence for

- Noise is a mechanical force, therefore subject to physical laws
- Mechano-transduction has a key role in the transmission of maintenance of structure, function and information in all living beings
- The information of a sound event arises from its complex qualities
- Low frequencies demonstrate increased conductivity in conductive structures such as actin fibres and microtubules
- An impulsive signal is more likely to be answered than a uniform signal
- The cardiovascular system is controlled and adjusted beat-to-beat
- Vital developments in the morphogenesis of the embryo are particularly susceptible to interferences not only for chemical substances or radiation, but also for external forces
- Overstimulation of PIEZO channels leads to gene expression with inflammatory mediators and thus intervene in processes of mutual reinforcement

- The low frequencies emitted by IWT`s lie within a frequency spectrum comparable to that of an animal organism, which means that there is a risk of resonance effects
- The effect of a stressor is independent of its conscious perception.

5.4. Evaluation of the Hypothesis

5.4.1. Positive Support for Evidence

Mechanotransduction which is responsible for many vital regulatory processes, has been scientifically proven [1,2,24,44,45]. Several international studies have shown that the transmission of *infrasound* is associated with verifiable stress reactions: infrasound interacts with cell metabolism and leads to perivascular fibrosis in *Infrasound induces coronary perivascular fibrosis in rats* according to Lousinha [70]. Similar findings are presented in [25,72,73]. Empiric data in experimental studies show clear indications that exposure to infrasound leads to a *ROS increase* [18,19,74]. Also, the study of Chaban et al. *indicates positive evidence by decreasing myocardial contractility of heart under Infrasound [75]* and the direct cell effect is shown in *the Effect of infrasound on the growth of colorectal carcinoma in mice* [76]. There is evidence for a direct cell and membrane effect in the review of Roos and Vahl [62]. A positive evaluation is also the *metanalysis* from Dumbrille et al. [60]: This evaluation results in the causality of *adverse health effects (ADH's)* and the stressor in *all "Bradford Hill criteria"*. Reported adverse effects on animals revealed not only stress reactions but also negative effects on *fertility, development, and reproduction* [76]. Positive evidence for the frequent occurrence of atrial fibrillation is presented in the *"nurse cohort study"* [78]. increased diastolic intracellular Ca^{2+} plus levels under infrasound [18,24,62]. A case study reports on a family in Ljungbyholm, southern Sweden, with a chicken farm. From 2009 to 2020, the normal hatch rate *after 21* days of incubation was at least 95%. After 12 turbines of 4.5 MW were commissioned at a distance of 950 metres, egg mortality was 100%. A direct link was established between the distance of the eggs to be hatched and the wind farm; noted by the Swedish authorities and published in a veterinary medicine journal 2024 {79]. Further positive support for evidence results from the re-evaluation of the pathohistological images from Alvez-Pereira and Branco [80,81] who examined the long-term effects of occupational exposure to infrasound and vibration in the context of the aircraft industry, known as *vibroacoustic syndrome. The pathohistological findings in FIG 13, FIG 14 and 15 confirm the effects of infrasound on cells and membranes.*

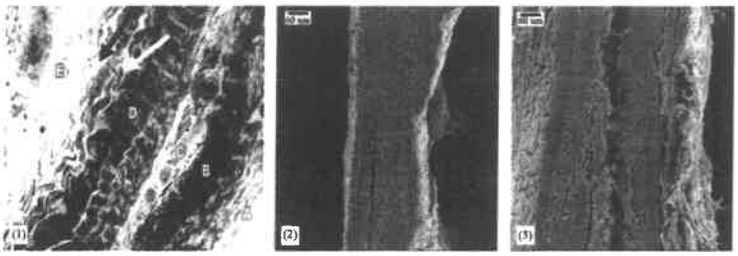


Figure 13. *Original description*: Light microscopy (100×)—VAD patient pericardium, with pericardial sac on right. Five (instead of the normal three) layers are identifiable: (A) mesothelial, (B) internal fibrosa, (C) loose tissue, (D) external fibrosa, and (E) epipericardium. The loose tissue is rich in vessels. No inflammatory cellularity was identified in any of the five layers. In both fibrous layers, wavy collagen bundles are visible, however the wave length of fibres in layer B (internal fibrosa) is smaller than that in layer D (external fibrosa). Taking together the increased amount of collagen bundles, in wavy, accordion-like arrangements, with different orientations in relation to each other, and with more than one elastic fibre accompanying the bundles at seemingly perpendicular angles (seen through electron microscopy, not shown), seems to suggest a pneumatic-like structure, designed to absorb abnormally large external forces. Similarly, this functional arrangement also explains why there is no diastolic dysfunction, despite the thickened pericardial walls. (2) SEM of non-VAD patient pericardium. Normal three layers are visible: mesothelium (white arrow), fibrosa (black arrow) and epipericardium. (3) SEM of VAD patient pericardium. Fibrosa has split into two halves (arrows) that sandwich a newly formed layer of loose tissue (L). [..]Remarks: ultrastructure micrographs, obtained with scanning (SEM) and transmission (TEM) electron microscopy. Pericardial wall in exposed and non-exposed persons 1) exposed (Light microscopy) 2) non-exposed (SEM) and 3) exposed (SEM)Alves-Pereira M., Branco C. (2007) Vibroacoustic disease: biological effects of infrasound and low-frequency noise explained by mechanotransduction cellular signalling http://www.sciencedirect.com/science/article/pii/S0079610706000927. [80] Page 11 FIG 2. With permission.

FIG 14 *Original description* (SEM) Non-exposed bronchial epithelium. The BC in the centre of the image exhibits a tuft of microvilli that are individually identifiable, uniformly distributed, and sprouting upward into the airway. Surrounding the BC are SC with microvilli of different sizes. Tufts of cilia featuring vesicles are also visible. No sheared, shaggy or wilted cilia are visible SEM). No oedema is present. *BC* (*brush cells*), *SC* (*Secretory cells*). Rat bronchial epithelium, exposed to 2160 h of continuous IFLN. With permission

FIG 15 *Original description* (SEM) Rat bronchial epithelium exposed to 2160 h of continuous ILFN. A *BC* is in the centre of the image. Its *microvilli* are not sprouting upward and, instead, have fused, forming a central indentation that seems to be spreading outward. The prominent *SC* that surrounds the *BC* are swollen forming deep valleys at the intercellular junctions. SC microvilli are very irregular. Ciliary vesicles are visible. *Ultrastructure micrographs, obtained with scanning (SEM) and transmission (TEM electron microscopy. BC (brush cells), SC (Secretory cells).* Rat bronchial epithelium, exposed to 2160 h of continuous IFLN. With permission.

A positive support for evidence is the state of scientific knowledge in PIEZO research, which has made significant progress in elucidating *mechanotransduction`s processes* in various organ systems (24, 52). Mechanotransduction regulates essential functions such as cell *division, migration, morphogenesis, vesicular transport, gene expression and fluid homeostasis*. Both the symptoms such as increased cardiovascular symptoms, blood pressure, cardiac arrhythmias, pericardial thickening can be conclusively explained for the first time. Systematically higher MI incidences, *not case fatalities,* in rural environment, are the result of myocardial-infarction-related mortality in Germany 2024 [82]. Data collection took place between 2012-2018 nationwide for all MI incidences and case fatalities.

The study from Weichenberger et al. 2017 shows the unconscious regarding and processing of infrasound beyond the acoustic perception threshold in certain brain structures [83].

Several current studies show comparable areas of influence that speak in favour of the infrasound factor as stressor. What the studies have in common is the affected radius of minimum 10 kilometers, also in the study [57].

1) The considerable decline in plant biomass production in all indicators of the current study [57] on over 100,000 IWT shows clear positive evidence for a negative influence of installed IWT`s on plant growth. Other factors such as changes in local surface temperature or moisture content add up to the effect of infrasound, but can be differentiated by the sphere of influence of infrasound, which always remains in the same radius [57].

2) A recent study (2023) shows a significant decline (63%) in the population of seabirds a) with loons within a 10-kilometre radius after the installation of new offshore wind turbines [84] and b) with kittiwakes: 46 offshore wind turbines also had a significant impact on the kittiwake (Rissa tridactyla), used in the current study showing a 45% decline in the observed area during the breeding season [85].

3) The Impact of Wind Farms on Suicide, Eric Zou, October (2017) [86].

5.4.2. Possibly Negative Support for Evidence

In [42] there is a small sample size, but the results are based on a careful study design and consistent results. Several studies about the possible *adverse health effects* (ADH's) of infrasound on its environment show contradictory results or do not show any effects when using infrasound. On closer inspection, the study designs and/or the used criteria, prove therefore to be unsuitable for their purpose. Investigations either used invalid frequency weightings such as dBA, were conducted *after* the impact *or* cannot reflect the influence on mechanotransduction processes because impact and measurement did not take place at the same. One example therefore is [87].

Regarding the question of the validity of computer-aided statements, we refer to Mazzag [44,45] for a detailed statement and our comment [5] regarding to this.

The current PIEZO research and vasomotion research is an ongoing process. The authors themselves point out corresponding limitations and partially contradictory results that require further research.

6. Established Methods to Assess and Visualize Microcirculatory Processes

The microcirculation can be visualized *in vivo* on new born babies via the skin, and on adults via the oral mucosa [2,14]. Appropriate techniques are video microscopy techniques such as *side stream dark field (SDF)* imaging [14]. A further visualization of vasomotion *in vivo* has become possible [15]. The *microcirculation* in the context of diseases can be visualized and quantified immediately after exposure to the stressor, as well as in its absence. Parameters that are be specifically observed, include:

- *The intact vasomotion in the first order*
- *An instantaneously changing in vasomotion under a defined stressor effect*
- *The functional blood vessel density (FVD) (mm/mm2)*
- *The red blood cell flow velocity (RBCV)*
- *The number of perfused capillaries (N/A) (n/mm^2)*
- *The capillary vessel diameter (DM)*
- *The glycocalyx thickness in nm (conceivable for further research projects)*

7. Proposed Research Avenues and Questions Regarding Target

- Direct experimental verification of endothelial mechanotransduction in on/off setting under impact with different low frequencies and different sound pressure
- Clarification of the issue, which sound pressure is required at a certain frequency to obtain a transfer response? Based on this: Below which frequency does a *particular danger for all living organisms exist (we call it a threshold frequency)*?
- What role do resonance effects play?
- Evaluation of pathohistological effects after longer exposition and increased markers for inflammation in the blood of mammals

8. Discussion

The information of a sound depends on its complex pattern, as well as its temporal occurrence. Low frequencies encounter particularly high conductivity in organic structures, which may be a reason why low frequencies below 10 Hz *have a particularly high information content.* Research results show an increasing transmission of infrasound through *actin filaments and microtubules* depending on the *depth of its frequency*, even to cell nuclei. It remains to be demonstrated that the transduction, as already calculated, leads to an increase in irregular information as the frequency decreases. This would mean an increasing incompatibility with foundations of life.

Many studies have already confirmed the stress effects of low frequencies and interactions with cellular structures and membranes.

The conversion into *partial irregular information* and a possible *overstimulation of PIEZO channel is a further logical and compelling step*. Since the frequencies of conventional IWTs are in a comparable range to the body's own frequencies, harmful resonance effects cannot be ruled out, in particular, interferences with the body's own hormone and protein production during sleep.

Much research is still needed to clarify the significance of *mechanotransduction`s processes* in individual organ regions, however the ongoing PIEZO channel research demonstrates already a high sensitivity to uncontrolled external forces esp. during embryogenesis, in the growing organism as a whole, in the cardiovascular system and in the neurological system according to its equipment with PIEZO channels.

It is state of the art that inadequate NO supply leads to an increase in *oxidative and oscillatory* stress which is an important prerequisite for the *loss of endothelial integrity* and consequently for all endothelial functions with consequences such as blood pressure increase, inflammation, arteriosclerosis, myocardium fibrosis, cardiac arrhythmia, myocardial infarction, stroke, infertility, immune deficiency and possibly cancer.

Over-additive effects must be taken into account, e.g., the possibility of an impact with alkylating substances and the already reduced resilience of the redox system under increased oxidative stress.

The shift in the inflammatory balance towards fibrosis in the event of increased tissue pressure and overstimulation by PIEZO channels in the direction of myocardial or pulmonary fibrosis, therefore takes on new significance in connection with mechanotransduction`s processes.

9. Conclusion

An organism can be viewed *both mechanically and energetically. Every atom vibrates.* Communication takes place through the *exchange of energy and forces*, which forms the basis for the *maintenance of structure and function* both within an organism and within a biosphere. The principle of undisturbed *mechanotransduction* is a fundamental prerequisite for all life functions.

The possibility of infrasonic frequencies being transmitted to mechano-sensor levels, is highly evident.

Depending on the individual's ability to compensate, exposure to a chronic stressor such as impulsive and periodic infrasound must lead to an exhaustion which manifests first in functional disorders of the substrate and oxygen supply, later on in an increasing loss of endothelial functions. New knowledge in a clinical context can contribute to behavioural changes e.g., awareness of high sensitivity to external forces, especially in the first trimester of pregnancy during *vasculogenesis* where a random event can have significant effects according to the stochastic principle. Another example is the risk of a workplace with vibrations and low frequencies that could aggravate cardiovascular diseases. Recent studies indicate that *humans, animals and plants* within a radius of *at least* 10 kilometers can be harmed by far reaching emissions through IWT techniques.

Since all organisms are equipped with mechanosensory systems, a further increase in far-reaching low frequencies in open-air and open-water situations is likely to pose a major *threat to biodiversity* as *a whole*. Marine ecosystems and also whales and dolphins are particularly vulnerable to low-frequency emissions from offshore installations due to the specific properties of hydroacoustic. It must be assumed that insects, bees and other pollinators are also affected which would mean a potential threat to a further fundamental basis of life. Urgent questions arise, such as the connection between the increase of cardiovascular diseases and neurological disorders, the decline of fertility, the decline in insect and bee populations and the plant biomass reduction in the affected surroundings. The common denominator is with high evidence *malfunctioning mechanotransduction`s process.* Appropriate preventive measures should be taken now, as stressors are currently present in the home environment well as open-air and open-water situation before all scientific questions are clarified. Sensitive groups must be the benchmark.

10. Acknowledgements

I would like to thank Christian Lehmann, PhD, MD, FRCPC, Department of Anesthesia, Pain Management & Perioperative Medicine , Faculty of Medicine, Department of Microbiology & Immunology , Department of Physiology and Biophysics , Department of Pharmacology, Dalhousie University, Halifax, Nova Scotia, Canada for his critical review and constructive contributions. I would also like to thank Manfred Krueger, graphic designer, Berlin for graphic FIG 2,4,7,8,9.

11. Disclaimer

For the author there are no conflicts of interests. The author would like to clarify that: Alternative forms of renewable energy are considered as worthful additions at suitable locations. The data reported herein have been scrutinized under one, and only one agenda, that of pure scientific inquiry. There are no commercial, financial or professional agreements.

References

1) Laurindo, F.R.M., Liberman, M., Fernandes, D.C. and Leite Paulo, F. Cap. 8. Endothelium-Dependent Vasodilation: Nitric Oxide and Other Mediators. In: Da Luz, P.L.,

Libby, P., Laurindo, F.R.M. and Chagas, A.C.P., Eds., *Endothelium and Cardiovascular Diseases. Vascular Biology and Clinical Syndromes*, Mica Haley, Sao Paolo,2018, 97-98

2) Nussbaum, C.F. (2017) Neue Aspekte der Mikrozirkulation im Rahmen von Entzündung, Entwicklung und Erkrankung. Kumulative Habilitationsschrift zur Erlangung der Venia Legendi. Fach Pädiatrie. Ludwig-Maximilians-Universität München. Kinderklinik und Kinderpoliklinik im Dr. von Haunerschen Kinderspital. München

3) Sperando, M. and Brandes, R. Cap. 20. Mikrozirkulation. In: Brandes, R., Lang, F., Schmidt, R.F., Eds., *Physiologie des Menschen mit Pathophysiologie*, Springer, (2019) Vol. 32, 241-256.

4) Bellut-Staeck, UM. Die Mikrozirkulation und ihre Bedeutung für alles Leben. Untertitel: Aktuelle Erkenntnisse zu lebenswichtigen Funktionen von Endothelzellen. In Series Titels: *Essentials. Publisher Springer Berlin, Heidelberg*; 2022. Available: https://doi.org/10.1007/978-3-662-66516-9.Softcover ISBN978-3-662-66515-2.

5) Bellut-Staeck, U. Impairment of the Endothelium and Disorder of Microcirculation in Humans and Animals Exposed to Infrasound due to Irregular Mechano-Transduction. *Journal of Biosciences and Medicines*, Volume **11**, 2023 30-56. Doi: 10.4236/jbm.2023.116003

6) Durán, W.N., Sánchez, F.A., Breslin, J.W., Microcirculatory exchange function. In: *Comprehensive Physiology*. Program in Vascular Biology; 2011 USA.

7) Fernandes, C.D., Araujo Thaıs, S., Laurindo, F.R.M. and Tanaka, L.Y.) Cap. 7. Hemodynamic Forces in the Endothelium. Mechanotransduction to Implications on Development of Atherosclerosis. In: Da Luz, P.L., Libby, P., Laurindo, F.R.M. and Chagas, A.C.P., Eds., *Endothelium and Cardiovascular Diseases. Vascular Biology and Clinical Syndromes*, Mica Haley, Sao Paolo, 2018, 85-94.

8) Moore, P.R., Dyson, A., Singer, M. and Frazer, J. Microcirculatory Dysfunction and Resuscitation: Why, When, and How. *British Journal of Anaesthesia*, **115**, 2015, 366- 375. https://doi.org/10.1093/bja/aev163

9) Voets, T. and Nilius, B. TRPCs, GPCRs and the Bayliss Effect. *The EMBO Journal*, **28**, 2009 4-5. https://doi.org/10.1038/emboj.2008.261

10) Chien, S. Mechanotransduction and Endothelial Cell Homeostasis: The Wisdom of the Cell. *The American Journal of Physiology-Heart and Circulatory Physiology*, 2007, **292**, H1209-H1224. https://doi.org/10.1152/ajpheart.01047.2006

11) De Wit, C., Hoepfl, B. and Wölfle, S.E. Endothelial Mediators and Communication through Vascular Gap Junctions. *Biological Chemistry*, **387**, 3-9. 2006, https://doi.org/10.1515/BC.2006.002

12) De Wit, C., Wölfle, S.E. and Höpfl, B. () Connexin-Dependent Communication within the Vascular Wall: Contribution to the Control of Arteriolar Diameter. *Advances in Cardiology*, 2006, **42**, 268-283. https://doi.org/10.1159/000092575

13) Aalkjaer, C. and Mulvany, M.J. (2020) Structure and Function of the Microcirculation. In: Agabiti-Rosei, E., Heagerty, A.M. and Rizzoni, D., *Microcirculation in Cardiovascular Diseases*, Springer, Berlin, 1-14.
https://doi.org/10.1007/978-3-030-47801-8_1

14) De Backer, D., Ospina-Tascon, G., Salgado, D., Favory, R., Creteur, J. and Vincent, J. (2010) Monitoring the Microcirculation in the Critically Ill Patient: Current Methods and Future Approaches. *Intensive Care Medicine*, 2010, **36**, 1813-1825.https://doi.org/10.1007/s00134-010-2005-3

15) Zhang Y-Y, Li J-Z, Xie H-Q, Wang W-T, Zhao B, Jia J-M. High-resolution vasomotion analysis reveals novel arteriole physiological features and progressive modulation of cerebral vascular networks by stroke. *Journal of Cerebral Blood Flow & Metabolism*. 2024, Vol. 44(11) 1330–1348. DOI: 10.1177/0271678X241258576

16) Donati, A., Damiani, E., Domizi, R., Romano, R., Adrario, E., Pelaia, P., Singer, M. Alteration of the sublingual microvascular glycocalyx in critically ill patients. *Microvascular Research*. 2013; 90: 86-89. Available: https://doi.org/10.1016/j.mvr.2013.08.007

17) Pries AR. Coronary Microcirculatory Pathophysiology: Can we afford it to remain a black box? *European Heart Journal*. 2016; 38:478-488. Available https://doi.org/10.1093/eurheartj/ehv760

18) Botts, S.R., Fish, J.E. and Howe, K.I. Dysfunctional Vascular Endothelium as a Driver of Atherosclerosis: Emerging Insights into Pathogenesis and Treatment. *frontiers in Pharmacology* Doi: 10.3389/fphar.2021.787541

19) Solberg, A., Rimereit, B.E., Weinbach, J.E. Leading edge erosion and pollution from wind turbine blades. *The turbine group 2021*. 5th edition.

20) Hamrangsekachaee, M., Wen, K., Bencherif, S.A., Ebong, E.E. Atherosclerosis and endothelial mechanotransduction: Current knowledge and models for future research. *American Journal of Physiology-Cell Physiology*. 2023 Feb 1; 324(2):C488-504

21) Pries, A.R., Coronary Microcirculatory Pathophysiology: Can we afford it to remain a black box? *European Heart Journal*. 2016; 38:478-488. Available:
https://doi.org/10.1093/eurheartj/ehv760

22) Augusto, O., Bonini, M.G., Amanso, A.M., Linares, E., Nitrogen dioxide and

carbonate radical anion: Two emerging radicals in biology. *Free Radical Biology and Medicine*. 2002; 32: 841-859

23) Wink, A.A. and Mitchell, J. Chemical Biology of Nitric Oxide: Insights into Regulatory, Cytotoxic, and Cytoprotective Mechanisms of Nitric Oxide. *Free Radical Biology and Medicine*, 1998, 25, 434-456. https://doi.org/10.1016/S0891-5849(98)00092-6

24) Fang1,2†, X.F., Zhou1,2†, T, Xu12, J.Q., Wang1,2, Y.W., Sun1,2, M.M., He1,2, Y.J. Pan1,2, S.W., Xiong1,2, W., Peng1,2Z.K., Gao1,2, X.H. and Shang1,2, Y. Structure, kinetic properties and biological function of mechanosensitive Piezo channels. *Cell Biosci 2021, 11:13,* https://doi.org/10.1186/s13578-020-00522-z

25) Liu, Z., Gong, L., Li, X., et al.. Infrasound increases intracellular calcium concentration and induces apoptosis in hippocampi of adult rats. *Molecular Medicine Reports*. 2012;5: 73-77. Available: https://doi.org/10.3892/mmr.2011.597

26) Espey, M.G., Miranda, K.M., Thomas, D.D., Miranda, K.M. and Wink, D.A. A Chemical Perspective on the Interplay between NO, Reactive Oxygen Species, and Reactive Nitrogen Oxide Species. *Annals of the New York Academy of Sciences*, 2002, **962**, 195-206. https://doi.org/10.1111/j.1749-6632.2002.tb04068.x

27) Guimarães Di Stasi, M., Pratschke, Acting cybernetically in architecture: Homeostasis and synergy in the work of Buckminster Fuller, Fuller RB *Cybernetics and Human Knowing*. 2020;27 :65-88

28) Shimizu, Y. and Garci, J.G.N. Cap. 1. In The Endothelial Cytoskeleton. Multifunctional Role of the Endothelial Actomyosin Cytoskeleton. In: Rosado, J.A. and Redondo, P.C., Eds., *Endothelial Cytoskeleton*, CRC Press, Boca Raton, 2014,1-26.

29) Wang, L. and Dudek, S.M. Regulation of Vascular Permeability by Sphingosine 1-Phosphate. *Microvascular Research*,2009, **77**, 39-45. https://doi.org/10.1016/j.mvr.2008.09.005

30) Lee, T.Y. and Gotlieb, A.I. Microfilaments and Microtubules Maintain Endothelial. *Microscopy Research and Technique*, 20360, 115-127.https://doi.org/10.1002/jemt.10250

31) Belvitch, P., Htwe, Y.M., Brown, M.E. and Dudek, S. Cortical Actin Dynamics in Endothelial Permeability. In: Belvitch, P. and Dudek, S., Eds., *Current Topics in Membranes*, Elsevier, Amsterdam, 2018 141-195.
https://doi.org/10.1016/bs.ctm.2018.09.003

32) Suthahar, N., Meijers, W.C., Silljé, H. and de Boer, R. From Inflammation to Fibrosis-Molecular and Cellular Mechanisms of Myocardial Tissue Remodelling and Perspectives on

Differential Treatment Opportunities. *Current Heart Failure Reports*, *2017,***14**, 235-250. https://doi.org/10.1007/s11897-017-0343-y

33) Ley, K., Laudanna, C., Cybulsky, M.I. and Nourshargh, S. Getting to the Site of Inflammation: The Leukocyte Adhesion Cascade Updated. *Nature Reviews Immunology*, **7**, 2007, 678-689. https://doi.org/10.1038/nri2156

34) Serhan, C.N., Brain, S.D., Buckley, C.D., Gilroy, D.W., Haslett, C., O'Neill, L.A., Perretti, M., Rossi, A.G. and Wallace, J. Resolution of Inflammation: State of the Art, Definitions and Terms. *FASEB Journal*, 2007,**21**

35) Nussbaum, C. and Sperando, M. Innate Immune Cell Recruitment in the Fetus and Neonate. *Journal of Reproductive Immunology*, 2011, **90**, 74-81.https://doi.org/10.1016/j.jri.2011.01.022

36) Nussbaum, C., Klinke, A., Matti, A., Baldus, S. and Sperando, M. Myeloperoxidase: A Leukocyte-Derived in the Resolution of Acute Inflammation. *Immunity*, 2013,**40**, 315-327

37) Buckley, C.D., Gilroy, D.W., Charles, N. and Serhan, C.N. Pro-Resolving Lipid Mediators and Mechanisms in the Resolution of Acute Inflammation. *Immunity*, 2014, **40**, 315-327. https://doi.org/10.1016/j.immuni.2014.02.009

38) Bellut-Staeck, U.M. Chronic Infrasound Impact is Suspected of Causing Irregular Information via Endothelial Mechano-transduction and Far-reaching Disturbance of Vascular Regulation in All Organisms. In*: Medical Research and Its Applications,* Vol. 8 Chapter **5.** Print: ISBN: 978-81-975566-2-3, eBook ISBN: 978-81-975566-5-4. 2024 DOI: https://doi.org/10.9734/bpi/mria/v8/727

39) Li, B., Sharpe, E.E., Maupin, A.B. et al. VEGF and PlGF promote adult vasculogenesis by enhancing EPC recruitment and vessel formation at the site of tumor neovascularization. *FASEB J 20*: 2006,1495–1497

40) Hahn, C., Schwartz, M.A. Mechanotransduction in vascular physiology and atherogenesis. *Nature Reviews Molecular Cell Biology*. 2009; 10: 53-62. Available: https://doi.org/10.1038/nrm2596

41) Likacs, V., Mao, R., Bayrak-Toydemir, P., Procter, M., Cahalan, S., Kim, H., Bandell, M., Longo, N., Day, R., Stevenson, D., Patapoutian, A., Krock, B., Impaired PIEZO1 function in patients with a novel autosomal recessive congenital lymphatic dysplasia JO - *Nature communications*, 2015.PY - 2015/09/21 VL - 6. DO - 10.1038/ncomms9329

42) Costa Pereira e Curto, T., Acquired flexural deformation of the distal interphalangeal joint in foals. *Dissertation Faculty of Veterinary Medicine.* 2012 Lisboa

43) ANNICHINO-BIZZACCHI J, VINICIUS DE PAULA E. 11. Blood Coagulation and Endothelium p 147-152. *Vascular Biology and Clinical Syndromes*. 2018, cap 11 S. 147-152. In ENDOTHELIUM AND CARDIOVASCULAR DISEASES. Edited by PROTA´ SIO L. DA LUZ.PETER LIBBY ANTONIO C. P. CHAGAS. FRANCISCO R. M. LAURINDO ISBN 978-0-12-812348-5

44) Mazzag B, Gouget C, Hwang Y, Barakat AI.. Mechanical force transmission via the cytoskeleton in vascular endothelial cells. Cap. 5 In: *Rosado JA, Redondo PC, Eds., Endothelial Cytoskeleton, CRC Press, Boca Raton*. 2014; 91-115.

45) Mazzag B, Barakat AI. The Effect of noisy flow on endothelial cell mechanotransduction: A computational study. *Annals of Biomedical Engineering*. 2010; 39: 911-921.Available: https://doi.org/10.1007/s10439-010-0181-5

46) Na, S., Collin, O., Chowdhury, F., Tay, B., Ouyang, M., Ouyang, M., Wang, Y. and Wang, N. Rapid Signal Transduction in Living Cells Is a Unique Feature of Mechanotransduction. *Proceedings of the National Academy of Sciences of the United States of America*, 2008, **105**, 6626-6631

47) Donati, A., Damiani, E., Domizi, R., Romano, R., Adrario, E., Pelaia, P. and Singer, M. Alteration of the Sublingual Microvascular Glycocalyx in Critically Ill Patients. *Microvascular Research*,2013, **90**, 86-89. https://doi.org/10.1016/j.mvr.2013.08.007

48) Ernfors P, El Manira AE, Svenningsson. Discoveries of receptors for temperature and touch. Scientific background. Karolinska Institutet Nobel Prize in Physiology or Medicine 2021. Last seen: https://www.nobelprize.org/prizes/medicine/2021/advanced-information/

49) Rode, B., Shi, J., Endesh, N., Drinkhill, P., Webster, P.J., Lotteau, S., *et al*. Piezo1 Channels Sense Whole Body Physical Activity to Reset Cardiovascular Homeostasis and Enhance Performance. *Nature Communications*, 2017, **8**, Article No. 350. https://doi.org/10.1038/s41467-017-00429-3

50) Philip, A. Gottlieb & Frederick Sachs. Piezo1, Channels, 2012, 6:4, 214-219, DOI: 10.4161/chan.21050

51) Moroni, M., Servin-Vences MR, Fleischer, R., Sanchez-Carranza, O, Lewin, G.R. *Voltage-gating of mechanosensitive PIEZO channels*. Now published *in Nature Communications,* 2018, doi: https://doi.org/10.1038/s41467-018-03502-7

52) Liu, H., Hu, J., Zheng, Q., Feng, X., Zhan, F., Wang, X., Xu, G. and Hua, F. Piezo1 Channels as Force Sensors in Mechanical Force-Related Chronic Inflammation. *Front. Immunol.* 13:816149.2022, Doi: 10.3389/fimmu.2022.816149

53) Raven, P.H, Ray, F, Eichhorn Biologie der Pflanzen 4. Auflage ISBN13 978-3-11-018531-7 De Gruyter 2006

54) Hamant1*, O. and Elizabeth S. Haswell2. E.S, Life behind the wall: sensing mechanical cues in plants. Hamant and Haswell. *BMC Biology* (2017) 15:59 Hamant and Haswell BMC Biology (2017) 15:59. DOI 10.1186/s12915-017-0403-5

55) Heng Zhang,1,2, * Yang Zhao,1,3 and Jian-Kang Zhu1,4. Thriving under Stress: How Plants Balance Growth and the Stress Response. *Developmental Cell*. 2020.DOI: https://doi.org/10.1016/j.devcel.2020.10.012

56) Khait,1,6,9 I., Lewin-Epstein,1,7,8,9, O., Sharon,1,2, R., Saban,1, K., Goldstein,1, R., Anikster,1, Y. Zeron,1, Y., Agassy,1, C. Nizan,1, S., Sharabi,1, G., Perelman,1, R., Boonman,3, A., Sade,1,4, N-, Yovel,3,5,10, Y., and Hadany1,5,10,11, L. * Sounds emitted by plants under stress are airborne and informative. *Cell press*. 2023 https://doi.org/10.1016/j.cell.2023.03.009

57) Gao 1,6, L., Wu 2,6, Q. Jixiang Qiu 1, Mei 3*, Y., Yao 1, Y., Meng 4, L. & Liu 5, P. (2023) The impact of wind energy on plant biomass production in China. *Scientific Reports* | (2023) 13:22366 | https://doi.org/10.1038/s41598-023-49650-9

58) Evans A. Environmental noise pollution: Has public health become too utilitarian? *Open Journal of Social Sciences*. 2017;5: 80-107. Available: https://doi.org/10.4236/jss.2017.55007

59) Persinger A, Infrasound, human health, and adaptation: an integrative overview of recondite hazards in a complex environment. *Nat Hazards.* 2014 70:501–525.DOI 10.1007/s11069-013-0827-3

60) Dumbrille, A, McMurtry, R.Y., Krogh, Marie C. Wind turbines and adverse health effects: Applying Bradford hill's criteria for causation. *Environmental Disease*. 2021; 6: 65-87

61) Pilger, C. and Ceranna, L. The Influence of Periodic Wind Turbine Noise on Infrasound Array Measurements. *Journal of Sound and Vibration*, **388**, 2017 188-200. https://doi.org/10.1016/j.jsv.2016.10.027

62) Roos, W. and Vahl, C.F Infraschall aus technischen Anlagen. Wissenschaftliche Grundlagen für eine Bewertung gesundheitlicher Risiken. *ASU Arbeitsmed Sozialmed Umweltmed*, 2021, **56**, 420-430. https://doi.org/10.17147/asu-2107-7953

63) Vanderkooy, J. and Mann, R. Measuring Wind Turbine Coherent Infrasound. (2014) *Measuring Wind Turbine Coherent Infrasound. Journal of Electromagnetic Analysis and Applications* Vol.1 No.2, June 25, 2009.

64) Krahé, D., Schreckenberg, D., Ebner, F., Eulitz, C., Möhler, U. (20149 Machbarkeitsstudie zu Wirkungen von Infraschall. Entwicklung von Untersuchungsdesigns für die Ermittlung der Auswirkungen von Infraschall auf den Menschen durch unterschiedliche Quellen. Verlag Umweltbundesamt; DOI: https://www.umweltbundesamt.de/publikationen/machbarkeitsstudie-zu-irkungenvon-infraschall

65) Eulitz; C. Zobel; P. Ost L., Möhler U., Schröder M. (2020) Ermittlung und Bewertung tieffrequenter Geräusche in der Umgebung von Wohnbebauung, TEXTE 134/2020, Umweltforschungsplan des Bundesministeriums für Umwelt, Naturschutz und nukleare Sicherheit. Forschungskennzahl 3713 53 100 FB000232

66) Schmitter; S., Alaimo; A., Hemmer D., Schreckenberg D., Großarth; A., Pörschmann; C., Kühner; T. Noise effects of the use of land-based Wind energy, Final Report. Texte 70/2022. Ressortforschungsplan of the Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection, Project Number 3717 43 110 0, Report No. FB000656/ENG.2022

67) Murugan NJ, Karbowski LM, Lafrenie RM, Persinger MA Temporally-patterned magnetic fields induce complete fragmentation in planaria. *PLOSone 2013*

68) Lurton; X. An Introduction to Underwater Acoustics, Principles and Applications. 2. Auflage. *Springer/Springer Praxis Books,* 2010, ISBN 3-540-78480-2

69) Katsnelson, B., Petnikov, V., Lynch, J.F., Low-Frequency Bottom Reverberation in Shallow Water. In book: *Fundamentals of Shallow Water Acoustics* (pp.239-266). January 2012. DOI: 10.1007/978-1-4419-9777-7_6

70) Louisinha, A., Oliveira, R.M..J, Borrecho, G, Brito J, Oliveira P, Oliveira da Carvalho, A., et al. Infrasound induces coronary perivascular fibrosis in rats. *Cardiovascular Pathology*. 2018;37: 39-44. Available: https://doi.org/10.1016/j.carpath.2018.10.004

71) Bowling, D.L. 1,2 Biological principles for music and mental health. *Translational Psychiatry.* 2023. 13:374; https://doi.org/10.1038/s41398-023-02671-4

72) Pei, Z, Chen, B.Y, Tie, R., et al Infrasound exposure induces apoptosis of rat cardiac myocytes by regulating the expression of apoptosis-related proteins. *Cardiovascular Toxicology*. 2011;11: 341-346.

Available: https://doi.org/10.1007/s12012-011-9126-y

73) Zhang, M.Y., Chen, C, Xie. X, J, et al. Damage to Hippocampus of rats after being exposed to infrasound. *Biomedical and Environmental Sciences*. 2016;29: 435-442.

74) Zhou, X, Yang, Q, Song, F., et al. Tetrahydroxystilbene glucoside ameliorates infrasound-induced central nervous system (CNS) injury by improving antioxidant and anti-inflammatory capacity. *Oxidative Medicine and Cellular Longevity*. 2020; Article ID: 6576718. Available: https://doi.org/10.1155/2020/6576718

75) Chaban, R., Ghazy, A., Georgiadem E, Stumpf N, Vahl CF. Negative effect of high-level infrasound on human myocardial contractility: *In vitro* Controlled Experiment. *Noise Health*. 2021;23: 57-66

76) Zhang H, Qi, P., Si, S.Y, Ma, W.M. Effect of infrasound on the growth of colorectal carcinoma in mouse. *Chinese Journal of Cancer Prevention and Treatment.* 2013; 20:1145-1149.

77) Bittner-Mackin, E. Excerpts from the final report of the township of lincoln wind turbine moratorium committee. Zoning Board of Appeals, Bureau County; 2006. Available: http://www.aweo.org/windlincoln.html

78) Bräuner, E.V., Jørgensen, J.T, Duun-Henriksen, A. K, Backalarz, C., Laursen, J.E., Pedersen, T.H., Simonsen, M.K, Andersen, Z.J. Long-term wind turbine noise exposure and the risk of incident atrial fibrillation in the danish nurse cohort. *Environment International*. 2019; 130: Article ID: 104915. Available: https://doi.org/10.1016/j.envint.2019.104915

79) Theorell H., Vemdal M. Why Does Egg Mortality Increase Near a New Wind Industry? Published in *"Svensk Veterinärtidning"* No 5 June 2024 Vol. 75. DOI: **https://www.svenskveterinartidning.se/wp-content/uploads/2024/06/SVT2405.pdf**

80) Alves-Pereira M, Branco C. Vibroacoustic disease: Biological effects of infrasound and low-frequency noise explained by mechanotransduction cellular signalling. *Progress in Biophysics and Molecular Biology*. 2007; 93: 256-279.DOI::https://doi.org/10.1016/j.pbiomolbio.2006.07.011
Available: http://www.sciencedirect.com/science/article/pii/S0079610706000927

81) Branco C, Alves-Pereira M. Low-frequency noise-induced pathology: Contributions provided by the portuguese wind turbine case. *Euronoise*. 2015, Maastricht, 31 May-3 June 2015, 2659-2661. Available:
https://www.researchgate.net/publication/290444707_Low_Frequency_Noise_
induced_Pathology_Contributions_Provided_by_the_Portuguese_Wind_Turbine_Case

82) Ebeling M, Mühlichen M. Talback, Rau R, Goedel A, Klüsener S. Disease incidence and not case fatality drives the rural disadvantage in myocardial-infarction-related mortality in

Germany. *Preventive Medicine* 179 (2024) 107833. 0091-7435/© 2024 The Authors. Published by Elsevier Inc. https://doi.org/10.1016/j.ypmed.2023.107833

83) Weichenberger, M., Bauer, M., Kühler, R., *et al.* Altered Cortical and Subcortical Connectivity due to Infrasound Administered near the Hearing Threshold—Evidence from fMRI. PLOS ONE, 2017 **12**, e0174420. https://doi.org/10.1371/journal.pone.0174420

84) Garthe, S., Schwemmer, H., Peschko, V. *et al.* Large-scale effects of offshore wind farms on seabirds of high conservation concern. *Sci Rep* 13, 4779 (2023). DOI: 10.1038/s41598-023-31601-z.9Vol.:(0123456789)Scientific Reports | (2023) 13:4779 | https://doi.org/10.1038/s41598-023-31601-zwww.nature.com/scientificreports/

85) Davies, J.G., Boersch-Supan, P.H., Clewley, G.D. *et al.* Influence of wind on kittiwake *Rissa tridactyla* flight and offshore wind turbine collision risk. *Mar Biol* **171**, 191 (2024). https://doi.org/10.1007/s00227-024-04508-0

86) *The Impact of Wind Farms on Suicide, Eric Zou, October 2017). http://documents.dps.ny.gov/public/Common/ViewDoc.aspx?DocRefId=%7BE0B0D0CF-55DC-E-9133-1F441547575%7D*

87) L. Ascone1*, C. Kling3, J. Wieczorek3, C. Koch3 & S. Kühn1,2. A longitudinal, randomized experimental pilot study to investigate the effects of airborne infrasound on human mental health, cognition, and brain structure, *Scientific Reports* | (2021) 11:3190 | https://doi.org/10.1038/s41598-021-82203-6

scientific reports

Check for updates

OPEN

Effects of low-frequency noise from wind turbines on heart rate variability in healthy individuals

Chun-Hsiang Chiu[1], Shih-Chun Candice Lung[1,2,3]✉, Nathan Chen[1], Jing-Shiang Hwang[4] & Ming-Chien Mark Tsou[1]

low frequency noise

close windows

Wind turbines generate low-frequency noise (LFN, 20–200 Hz), which poses health risks to nearby residents. This study aimed to assess heart rate variability (HRV) responses to LFN exposure and to evaluate the LFN exposure (dB, L_{Aeq}) inside households located near wind turbines. Thirty subjects living within a 500 m radius of wind turbines were recruited. The field campaigns for LFN (L_{Aeq}) and HRV monitoring were carried out in July and December 2018. A generalized additive mixed model was employed to evaluate the relationship between HRV changes and LFN. The results suggested that the standard deviations of all the normal to normal R–R intervals were reduced significantly, by 3.39%, with a 95% CI = (0.15%, 6.52%) per 7.86 dB (L_{Aeq}) of LFN in the exposure range of 38.2–57.1 dB (L_{Aeq}). The indoor LFN exposure (L_{Aeq}) ranged between 30.7 and 43.4 dB (L_{Aeq}) at a distance of 124–330 m from wind turbines. Moreover, households built with concrete and equipped with airtight windows showed the highest LFN difference of 13.7 dB between indoors and outdoors. In view of the adverse health impacts of LFN exposure, there should be regulations on the requisite distances of wind turbines from residential communities for health protection.

Wind energy is used around the world as a source of clean energy. However, wind turbines generate low-frequency noise (LFN) in the range of 20–200 Hz[1–4]. As many community complaints have centered around the LFN from wind turbines[5], it is important to evaluate the health impacts of LFN on residents near wind farms.

LFN exposure has been found to cause a variety of health conditions. Exposure to LFN from wind turbines results in headaches, difficulty concentrating, irritability, fatigue, dizziness, tinnitus, aural pain sleep disturbances, and annoyance[6–19]. Clinically, exposure to LFN from wind turbines may cause increased risk of epilepsy, cardiovascular effects, and coronary artery disease[20,21]. It was also found that exposure to noise (including LFN) may have an impact on heart rate variability (HRV)[22,23]. HRV is the variation over time of the period between adjacent heartbeats[24], which is an indicator of the activities of the autonomic nervous system, consisting of the sympathetic nervous system (SNS) and parasympathetic nervous system (PNS). Autonomic imbalance usually represents a hyperactive SNS and a hypoactive PNS and results in reduced HRV. An autonomic imbalance may increase the morbidity and mortality of cardiovascular diseases[25]. A review paper indicated that road traffic noise may overactivate the hypothalamic-pituitary-adrenocortical axis (HPA) and sympathetic-adrenal-medullar axis (SAM), increase the blood pressure and reduce HRV, and finally affect the cardiovascular system[26]. A recent study analyzing 658 measurements of HRV obtained from 10 healthy males (18–40 years old) indicated reductions in HRV due to environmental LFN exposure[27]. However, few studies have specifically examined the effect of LFN from wind turbines on HRV in healthy individuals; thus, this was the aim of this study.

In view of the adverse health impacts of noise exposure, many countries and international organizations have established regulations for noise control. These regulations are set for noise in the full spectrum of human hearing (20–20 k Hz). The Ministry of Environment of Finland set limits for wind farm noise of 45 dB (L_{Aeq}) during the day and 40 dB (L_{Aeq}) during the night[28]. In the United Kingdom, the fixed limit for turbine noise is 40 dB (L_{Aeq}) for the daytime and 43 dB (L_{Aeq}) for the nighttime[29]. In the United States, noise levels of ≤ 55 dB (L_{Aeq}) are set for outdoors in residential areas, farms, and other outdoor areas as requisites for public health protection, and levels of 45 dB are set for indoor residential areas, hospitals, and schools[30,31]. In addition to the full noise spectrum, the Taiwan Environmental Protection Administration (EPA) also established regulations for LFN to avoid impacts on residents, since wind farms have been set up very close to residential communities. The LFN

[1]Research Center for Environmental Changes, Academia Sinica, Taipei, Taiwan. [2]Department of Atmospheric Sciences, National Taiwan University, Taipei, Taiwan. [3]Institute of Environmental Health, National Taiwan University, Taipei, Taiwan. [4]Institute of Statistical Science, Academia Sinica, Taipei, Taiwan. ✉email: sclung@rcec.sinica.edu.tw

I-18

standards for wind turbines in the daytime (7 a.m.–7 p.m.) and evening (7 p.m.–10 p.m.) are 39 dB (L_{Aeq}) for environments requiring tranquility such as residential areas, 44 dB (L_{Aeq}) for mixed residential and commercial/industrial areas, and 47 dB (L_{Aeq}) for industrial areas; those at nighttime (10 p.m.–7 a.m.) are 36, 36, 41, and 44 dB (L_{Aeq}), respectively[32]. This study assessed the LFN in the indoor environments of households near wind turbines to evaluate whether the LFN levels meet the Taiwan EPA standards.

One of the most important factors influencing residential noise exposure from wind turbines is the distance of the wind turbine from the observer[33]. For example, at a distance of 120–500 m, the measured turbine noise levels decreased by 3–5 dB (L_{Aeq}), while at a distance of 1000 m the noise was reduced by 6–7 dB (L_{Aeq})[34]. Hansen et al. reported variations in indoor LFN levels (15–45 dB (L_{Aeq})) for two households (houses made of sandstone/concrete/iron or bricks with windows remaining closed or half open) at different distances from wind turbines[35]. This study assessed the indoor/outdoor differences in LFN exposure in several households located at varying distances from wind turbines. Our main focus was on the indoor LFN levels in several recruited households; we did not intend to conduct a comprehensive evaluation of the influential factors. These households serve the purpose of demonstrating the potential impacts of influential factors.

Besides distance from turbines, building materials also affect indoor LFN exposure. This work assessed the indoor LFN levels for several recruited households with different building materials and open/closed windows to illustrate their potential impacts. It is known that materials have different sound absorption coefficients[36]. The overall sound pressure level and spectrum of external noise change when transmitted to the interior of a building[37]. Mid- and high-frequency noises are selectively attenuated by roofs and walls, causing the building structure to function like an LFN pass filter[38]. Outdoor to indoor noise reduction generally decreases with frequency, which is related to housing construction and room dimensions[35]. Factors contributing to indoor/outdoor noise reduction also include structural resonances, room modes, and coupling between the air volume inside the residence and the stiffness of the walls, roofs, and ceilings[35]. It is known that the appropriate choice of construction materials and designs can contribute to LFN exposure reduction for residents. Hence, these factors are not evaluated comprehensively in this study.

Taiwan is a small and highly populated island. Wind farms have been set up near residential communities, affecting the day-to-day lives of the residents. The hypothesis of this study is that LFN from wind turbines might affect HRV of residents. In order to verify the hypothesis of this study, we defined two objectives: to evaluate the LFN and HRV relationship with an intervention design and to assesses the actual LFN exposure of the community residents. This investigation is the first in Asia examining the impact of LFN from wind turbines on the HRV of healthy residents. In addition, the variations in LFN exposure inside several residences constructed of different building materials are examined. The findings of this study would serve as a useful reference for Asian countries planning to launch or promote wind power generation.

Materials and methods

The following sub-sections describe the study design, monitoring equipment, LFN and HRV monitoring strategies, household LFN exposure monitoring, and data analysis.

Study design. There were two types of field monitors used in this work. The first one was used to assess the changes in HRV of the recruited subjects while taking LFN measurements at the same time at two designated sites with an intervention design; this is called "LFN and HRV monitoring". The second one was used to assess the LFN levels in the indoor and outdoor environments of several households; we intended to use it to assess whether the daily LFN exposures of residents were at the same range as those obtained in the first intervention monitoring.

Environmental monitoring devices. The sound level meter NL-62 (Rion, Japan), which complies with the IEC 61672-1, 2002 Class 1 and ISO 7196: 1995 applicable standards, was used for measuring the LFN. Measurements were analyzed using the frequency analysis program NX-62RT, with the choice of 1/3 of an octave and at intervals of 100 ms. Its band central frequencies were 20, 25, 31.5, 40, 50, 63, 80, 100, 125, 160, and 200 Hz. In addition, windscreens WS-10 and WS-15 were used in indoor and outdoor measurements, respectively, and equipped with rainproof features[39] to reduce the wind noise. The average acoustical intensity (dB, L_{Aeq}) was measured over a 5 min period. Moreover, the wind speed in the outdoor environment was measured by a wind speed smart sensor (S-WSB-M003), while the temperature and relative humidity (RH) in both indoor and outdoor environments were obtained using HOBO U12 data loggers (Onset Computer Corporation, Bourne, MA). Meteorological data were collected at a 5 min resolution.

HRV monitoring device. RootiRx (RootiCare®, Rooti Labs Ltd., Taipei, Taiwan), a wearable electrocardiogram (ECG) recorder, was employed to provide data on heart rate, HRV indicators, and motion in three dimensions (https://www.rooticare.com). RootiRx has received medical-device certifications from the EU, the US, and Taiwan. This compact device (62 × 22.5 × 8.45 mm, 14 ± 1 g) is attached to an electrode sticker (32.7 × 115 × 5.2 mm, 3.2 g) and can operate under a temperature of 0–40 °C and an RH of 20–93%. RootiRx has been evaluated against a standard 12-lead Holter monitor in 33 healthy subjects for 24 h[40]. The overall average beat per minute correlation between BeyondCare® (another name for RootiRx) and the standard 12-lead Holter was found to be 0.98. The mean percentage of invalid measurements was 1.6% for RootiRx and 1.7% for Holter. These findings indicate that the overall performance of RootiRx and Holter is similar. Moreover, the same study used RootiRx to assess cardiac arrhythmias in 67 subjects. The mean analyzable wear time was found to be 93.6%, and its water-resistant design enabled 73.5% of the participants to take a shower[40]. It was used in our

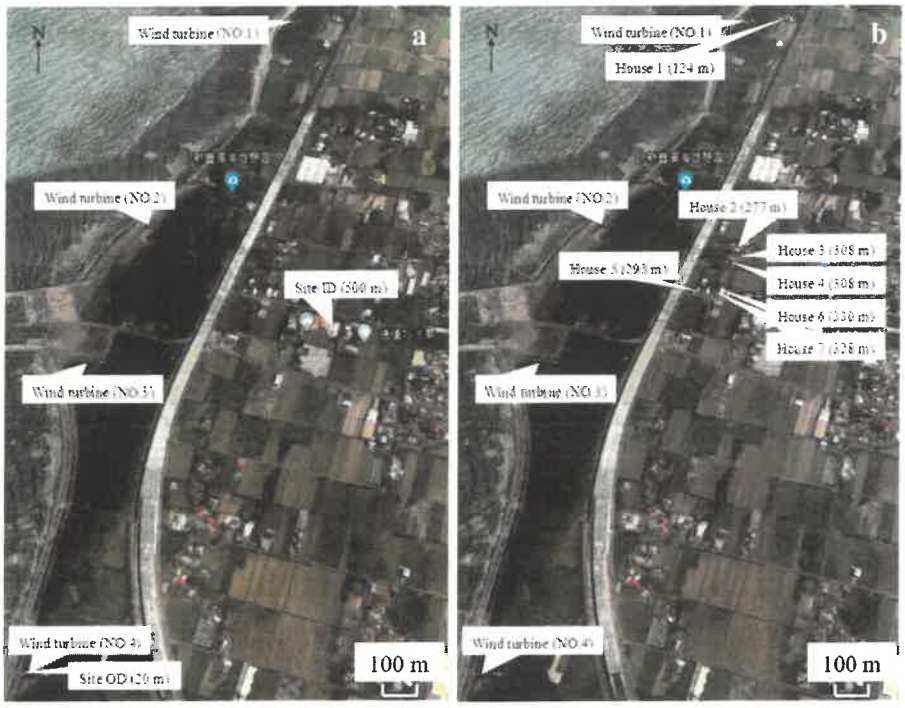


Figure 1. Schematics showing the locations of **(a)** field monitoring sites and **(b)** household monitoring residences relative to wind turbines[69].

earlier work to assess impacts on HRV from air pollution[41]. We applied RootiRx for subjects recruited in a community close to wind turbines.

All the ECG signals collected from RootiRx at the sampling rate of 500 Hz were downloaded and analyzed using previously validated proprietary algorithms provided by Rooti Labs Limited[40]. After automatically producing the data of HRV indices and excluding the artifacts (non-normal beats signals) by the proprietary algorithms, experienced research scientists in Rooti Labs Limited reviewed each batch of data. Overall, the sampling frequency (> 200 Hz) and duration of recording for investigating short-term HRV (5 min) met the recording requirements in the guidelines of the Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology[42], and the quality of RootiRx was compared to that of the standard Holter monitor as mentioned above[40].

LFN and HRV monitoring. The targeted community was located within a 500 m radius of wind turbines in western Taiwan. Public recruitment meetings were held to introduce our study objectives and plan. The inclusion criteria were residents aged between 20 and 80 years and non-smokers. The exclusion criteria were hearing impairments, high blood pressure, known heart disease, history of heart attack and heart surgery, irregular heart rhythm, and medications taken that would affect HRV. Thirty subjects were recruited with written informed consent. Then, face-to-face interviews were conducted to obtain detailed demographic data as well as information on the building materials of the residences, the types of windows installed, and the residents' habits of keeping windows open or closed (√: fully open; x: slightly open or fully closed). This study was designed and conducted complying with the guidelines of the standards set by the latest revision of the Declaration of Helsinki of the World Medical Association and was reviewed and approved by the Institutional Review Board of Academia Sinica (IRB No. AS-IRB01-18025). All participants in this study provided signed informed consent.

The field campaigns for LFN and HRV monitoring were carried out in July (summer) and December (winter) 2018. In each month, the field campaign lasted for two days on the first weekend of the month and was repeated again on the third weekend. Two sites were selected: an outdoor site (Site OD) and an indoor site (Site ID). Figure 1a illustrates the locations of two sites relative to the wind turbines. The distances were measured from the nearest wind turbine. Site OD was located in close proximity to the wind turbines 20 m away, where people would be exposed to relatively high levels of LFN. In contrast, Site ID was located at a distance of 500 m from the wind turbines; thus, people would be exposed to relatively low levels of LFN. The two sites were about a 5 min drive apart. The recruited subjects were gathered on the two sites to acquire different levels of LFN exposure, as described below. This intervention design aimed to make sure the subjects were exposed to LFN from wind turbines during our monitoring periods in a similar manner to residents who live near wind turbines in their daily lives are.

On Day 1, RootiRx was patched onto the chest of each subject at Site ID. Then, all the subjects were instructed to fill out a time-activity diary (TAD) at 30 min intervals regarding their microenvironments, activities, and

major exposure sources encountered, if any, during that 30 min period. The exposure sources listed included vehicles, electronics, wind turbines, machines, trains, aircrafts, music, conversations, and others (please specify).

On Day 2, all subjects gathered first at Site ID, the activity center of the study community. They were equally assigned into two groups, Group A and Group B, with similar age and gender distributions. Then, Group A was taken to Site OD. Transport was provided when shuttling between the two sites to avoid their HRV being affected by other factors. At both sites, the subjects were asked to sit in the chairs provided and the 1-h LFN monitoring commenced. The LFN levels were matched to the HRV of the subjects to assess the associations of HRV and LFN in a later data analysis. To prevent exposure to sunlight from affecting the subjects' HRV, a tent was pitched for monitoring at Site OD. Subjects were engaged only in low-intensity activities during the monitoring. At Site OD, subjects had their heights, weights, and blood pressures measured in the tent, while at Site ID, they listened to a talk on different types of energy and their applications. These activities were not vigorous and would not cause mood swings, thus having a minimum impact on HRV. According to our observations, all subjects were sitting or performing low-intensity activities that had minimal impact on the HRV during the monitoring at Site OD and Site ID. We tried our best to maintain similar conditions for both groups. Nevertheless, environmental factors could differ, such as temperature, humidity, and wind speed. After an hour, the two groups swapped sites, with Group A taken to Site ID and Group B to Site OD, and another one-hour LFN monitoring was repeated. At the end of monitoring on Day 2, RootiRx was removed from each subject. For field campaigns conducted in December, warm drinks were provided at both sites to minimize the effect of cold weather on subjects' HRV.

The environmental LFN levels were simultaneously measured at each site when the subjects wearing RootiRx gathered, as described above. In addition, environmental variables, including wind speed, temperature, and RH, were measured during field campaigns at both sites. At Site OD, instruments, including Rion NL-62, HOBO U12, and HOBO S-WSB-M003, were set up 3 m from the subjects about 1.7 m above the ground (roughly the height of human ears); meanwhile, at Site ID, instruments, including Rion NL-62 and HOBO U12, were set up on a table 1 m above the ground, approximately 2 m from the wall, and 3 m from the subjects.

It is noteworthy that regular LFN patterns (waves with an amplitude of 1–2 dB) occurred due to the running of the wind turbines. Additionally, the LFN from wind turbines is affected by wind speeds; the observed regular patterns moved gradually up or down, changing with wind speeds. If certain peaks occurred within these regular patterns, they were presumably from other sources (such as road vehicles and aircraft)[41]. We checked the raw data visually and manually and removed those sudden peaks. The percentage excluded was below 1%. After these quality control and quality assurance procedures, we were confident that the LFN in our dataset was from wind turbines rather than from other sources.

Household LFN exposure monitoring. The purpose of the household indoor and outdoor monitoring was to assess whether the everyday LFN exposures of residents were in similar ranges to the LFN exposures measured in the aforementioned field monitoring, which purposely staged the subjects staying at site OD. To assess the actual LFN exposure of subjects in their everyday life, the continuous 48-h monitoring of indoor and outdoor LFN was conducted in households in August–September (summer) and December (winter). Among 30 subjects, only seven households agreed on household monitoring. The distances of these seven households from the nearest wind turbine are shown in Fig. 1b, from 124 (House 1) to 330 m (House 6). Three households were monitored in summer and six in winter, with two residences (Houses 3 and 5) monitored in both seasons. For outdoor monitoring, the Rion NL-62 was set up approximately 2 m from the outside walls of the studied households at 1.7 m above ground. For indoor monitoring, Rion NL-62 was set up on a table in the living room of the studied households about 2 m from the wall at 1 m above ground. In order to avoid testing bias in real world situations for indoor and outdoor monitoring that had different temperatures, humidity, and wind speeds, we tried our best to maintain similar conditions such as instrument parameter settings and monitoring height and time.

Data analysis. Data cleaning procedures were carried out for the LFN and HRV data. The 5 min environmental variables (LFN (L_{Aeq}), temperature, RH, and wind speed) were calculated by averaging the data collected each minute during field campaigns. Though driven by winds of varying speed, wind turbines rotate steadily, and the LFN thus generated should be regular and uniform. A sudden increase in the LFN level exceeding 10 dB (L_{Aeq}) should be attributed to other sources (such as road vehicles and airplanes). Therefore, to ensure that the LFN data collected during field campaigns were from wind turbines, acute rises in the LFN of more than 10 dB (L_{Aeq}) at Site OD were excluded from data analysis. This exclusion criterion was not applied to Site ID, where diverse sources of LFN, as described later, were present, resulting in wider variations and more irregularity in the LFN trends observed.

The HRV responses to LFN exposures were assessed using a time-domain parameter, namely, the standard deviation of all normal to normal R-R intervals (SDNNs); and a frequency-domain parameter, namely, the ratio of low-frequency (LF; 0.04–0.15 Hz) to high-frequency power (HF; 0.15–0.4 Hz) (LF/HF). Even though breathing rate may affect the short-term time-domain measurements, LF and HF[24], previous studies nonetheless found that short-term exposure to $PM_{2.5}$ was significantly associated with the decreases in SDNN and/or increases in LF/HF[41,43–45]. In addition, subjects were asked to only engage in low-intensity activities in the field campaigns, and they had to complete the time-activity diaries to record their activities. Moreover, the activity intensity of subjects was considered in the models to control the subjects' breathing rate. Since SDNN is the most commonly used HRV index and LF/HF reflects the sympatho-vagal balance, we selected SDNN and LF/HF as the indicators in this study. Abnormal data with SDNNs greater than 250 and an LF/HF smaller than 0.1 were excluded from the analysis. HRV data in 5 min intervals with a missing rate greater than 20% were not included in further analysis[40]. After data cleaning, the average analyzable wear time of RootiRx in this work was 86.2%. Signal loss was attributed to the poor contact of the RootiRx patch worn by subjects in action. The data for LFN

Variable	Summer (n = 574)			Winter (n = 685)		
	Mean ± SD	Min	Max	Mean ± SD	Min	Max
Age (years)	54 ± 14	22	75	59 ± 14	33	75
BMI (kg/m^2)	23.9 ± 2.8	19.0	30.3	24.3 ± 2.9	21.1	34.0
Temperature (°C)	35.8 ± 3.9	31.5	41.0	22.6 ± 1.5	19.6	24.7
Relative humidity (%)	55.6 ± 10.6	40.8	67.2	73.5 ± 3.4	66.9	80.8
Wind speed (m/s)	0.95 ± 0.78	0	2.01	0.72 ± 0.79	0	2.42
Activity intensity (mG)	1891 ± 398	1201	3546	1781 ± 337	1173	3323
SDNN (ms)	61.7 ± 29.4	8.9	167.3	66.5 ± 29.2	11.7	180.9
SDNN at site OD (ms)	65.3 ± 30.8	8.9	167.3	68.8 ± 31.4	11.7	180.9
SDNN at site ID (ms)	55.8 ± 26.1	11.4	144.5	64.2 ± 26.5	12.8	146.7
LF/HF	1.9 ± 2.2	0.08	19.1	1.1 ± 1.2	0.09	13.3
LF/HF at site OD	1.7 ± 2.1	0.1	19.1	1.1 ± 1.3	0.1	13.3
LF/HF at site ID	2.1 ± 2.4	0.1	14.2	1.2 ± 1.1	0.1	8.5
LFN (L_{Aeq}, dB)	46.1 ± 4.1	38.3	53.5	45.8 ± 6.1	38.2	57.1
LFN at site OD (L_{Aeq}, dB)	43.5 ± 2.9	38.3	53.5	49.1 ± 6.9	40.5	57.1
LFN at site ID (L_{Aeq}, dB)	50.4 ± 0.8	48.6	52.5	42.3 ± 1.8	38.2	45.5

Table 1. Demographic characteristics of study subjects and environmental and LFN measurements with a 5 min resolution (n = 1259). Site OD: 20 m from wind turbines; Site ID: 500 m from wind turbines. *BMI* body mass index, *mG* milli-gravitational constant, 6.674×10^{-14} m^3/kg s^2, *SDNN* standard deviation of normal to normal R–R interval in 5 min resolution, *LF/HF* low frequency to high frequency ratio in 5 min resolution, *LFN* levels of the entire monitoring period.

and HRV indicators were matched in 5 min intervals for exposure-health evaluation. Studies indicated that the 5 min HRV, as compared to a 24-h measurement, was a strong indicator of cardiac events in the normal population and patients[46–49]. Long-term (24 h) measurements for HRV reflect the overall change in the heart rate under nonspecific, changing conditions, and short-term measurements offer more practical advantages, including easy application in a clinical setting and a simplified data process[49,50].

The associations between LFN and $\log_{10}$-transformed HRV indicators (SDNN and LF/HF) in 5 min intervals were analyzed using the general additive mixed model (GAMM, R Version 3.5.0). The model was adjusted for wind speed, temperature, age, gender (female was coded as 0 and male as 1), body mass index (BMI, body weight/(height^2) < 24 was coded as 0 and ≥ 24 as 1), activity intensity (mG: milli-gravitational constant, 6.674×10^{-14} m^3/kg s^2), and the interaction term of age and activity intensity. Activity intensity and temperature were adjusted using thin-plate spline in the GAMM models for $\log_{10}$(SDNN) and $\log_{10}$(LF/HF), respectively, as these variables were statistically significant in that model. Subjects were treated as random effect intercepts to adjust for individual differences. The cut-off for BMI was 24, following the guidelines of the Ministry of Health and Welfare, Taiwan, which takes BMI ≥ 24 as overweight[51]. Moreover, in view of the strong correlation between temperature and RH, RH was excluded from the model. The effect estimate (β) of LFN was transformed into the percentage change of HRV indicator per interquartile range (IQR) of the corresponding covariate, which can be presented as $\left[10^{(\beta \times \mathrm{IQR})} - 1\right] \times 100\%$. The corresponding 95% confidence interval (CI) was presented as $[10^{(\beta \mp 1.96 \times SE) \times \mathrm{IQR}} - 1] \times 100\%$, where *SE* is the standard error of the β estimate. Note that three asterisks (***), two asterisks (**) and one asterisks (*) showed $p < 0.001$, $0.001 < p < 0.05$, and $0.05 < p < 0.1$, respectively in the statistical analysis.

For household monitoring, indoor and outdoor LFN (dB, L_{Aeq}) measurements obtained from the 48 h monitoring were divided into three different time periods, namely, daytime (7 a.m. to 7 p.m.), evening (7 p.m. to 10 p.m.), and nighttime (10 p.m. to 7 a.m.), for comparison against the LFN standards designated by the Taiwan EPA. Moreover, the impacts of building materials, types of windows, and habits of keeping windows open or closed on the LFN indoor/outdoor differences were explored. In view of the insignificant effect of slightly open windows on LFN transmission[52], slightly open and fully closed windows were grouped into the same category in contrast to fully open windows.

Results

Distribution of demographics, LFN and HRV data. Among the 29 subjects recruited, 11 males and 13 females participated in the summer field campaign, while 9 males and 10 females participated in the winter field campaign, with 14 subjects (8 males, 6 females) participating in both seasons. Among the 29 subjects recruited in our study, LFN and HRV monitoring was carried out for 2 h (at Site OD and ID). In addition, the environmental and LFN measurements were in 5 min resolution. The ideal sample sizes of LFN and HRV monitoring were 1460. However, abnormal data with SDNNs greater than 250, an LF/HF smaller than 0.1, and HRV data in 5 min intervals with a missing rate greater than 20% were excluded from the analysis. After data cleaning, the actual sample size was 1259 (Table 1). Table 1 lists the demographic characteristics of the subjects. The age of the subjects ranged from 22 to 75 years. The average BMI of subjects was 23.9 ± 2.8 kg/m^2 in summer and 24.3 ± 2.9 kg/m^2 in winter. As shown in Table 1, for the summer and winter measurements, the mean SDNNs were 61.7 and 66.5 ms, while the mean LF/HFs were 1.9 and 1.1, respectively. The mean levels of LFN exposure were 43.5 ± 2.9

	Coefficient estimate	
	5 min SDNN	5 min LF/HF
LFN[a]	−3.39** (−6.52 to −0.15)	−0.37 (−6.44 to 6.10)
Wind speed	12.7*** (7.80 to 17.9)	-9.07* (-17.6 to 0.37)
Temperature	−0.025 (−4.20 to 4.34)	–[d]
Age	−6.43 (−23.1 to 13.8)	−31.5** (−48.4 to −9.11)
Gender[b]	−5.02 (−25.5 to 21.07)	58.7** (11.8 to 125.4)
BMI[c]	2.17 (−8.80 to 14.4)	−2.73 (−17.5 to 14.6)
Activity intensity	–[d]	−8.29*** (−12.6 to −3.81)

Table 2. Estimated percentage changes (95% CI) in (a) the 5 min SDNN and (b) the 5 min LF/HF per interquartile range (IQR) (7.86 L_{Aeq}, dB) increase in LFN (n = 1259). ***: $p < 0.001$; **: $0.001 < p < 0.05$; *: $0.05 < p < 0.1$. [a]LFN was treated as a continuous variable. [b]Gender: female was coded as 0 and male as 1. [c]BMI < 24 was coded as 0 and BMI ≥ 24 as 1. [d]Temperature and activity intensity were adjusted using thin-plate spline for SDNN and LF/HF GAMM models, respectively.

at Site OD and 50.4 ± 0.8 dB (L_{Aeq}) at Site ID in summer and 49.1 ± 6.9 and 42.3 ± 1.8 dB (L_{Aeq}), respectively, in winter. According to previous studies, these three factors are important factors for HRV[41,44,53]. The distributions of age, gender, and BMI in summer and winter are shown in Supplementary Table S1. Although these distribution factors were not significantly different between summer and winter, these factors were still included in the following GAMM analysis.

Impacts of LFN exposure on HRV. One of the main objectives of this study was to evaluate the potential impacts of LFN on HRV in terms of SDNN and LF/HF. Table 2 shows the 5 min percentage changes of HRV indicators per interquartile range (IQR) increase in LFN. GAMM analysis yielded 7.86 dB (L_{Aeq}) as the IQR of LFN. After adjusting for confounding factors, the SDNN was reduced by 3.39% (95% CI: 0.15–6.5%) per 7.86 dB (L_{Aeq}) of LFN with a statistical significance of $p < 0.05$. In other words, with an increase of 1 dB (L_{Aeq}) in LFN, the SDNN decreased by 0.43%. In contrast, the reduction in LH/HF per IQR increase in LFN was much smaller and not statistically significant. These results revealed a significant association between LFN exposure and changes in HRV, especially in SDNN, indicating the potential health impacts of exposure to LFN.

LFN exposure in residential households. In order to assess whether the subjects' daily LFN exposure was in a similar range to our "LFN and HRV monitoring", we conducted household LFN exposure monitoring for seven recruited households. The households' average LFN levels were 34.8 ± 6.9 dB and 43.4 ± 5.7 dB for indoors and outdoors, respectively. As shown in Table 3a, the indoor LFN exposure during the 24-h period among different households ranged from 30.7 to 43.4 dB (L_{Aeq}). Moreover, the maximum indoor LFN exposure of residents in their households in the daytime ranged between 39.7 and 56.7 dB (L_{Aeq}), which was similar to the range recorded at Site ID (38.2 and 52.5 dB). As shown in Table 3b, the outdoor LFN measured during a 24-h period among different households ranged from 38.2 to 50.0 dB (L_{Aeq}) in summer and 38.9 to 44.6 dB (L_{Aeq}) in winter. These household data were slightly lower than the field results at Site OD (38.3–53.5 dB, L_{Aeq}, in summer and 40.5–57.1 dB, L_{Aeq}, in winter), which was located much closer (20 m) to the turbines than the households. As shown in Table 3c, the CN residences (Houses 1, 2, 6, and 7) had larger indoor–outdoor differences (range, 6.6–11.2 dB (L_{Aeq})) than the concrete with brick (CB) residence (House 3; (range, 5.8–8.5 dB (L_{Aeq})). The results indicated that CN had a higher LFN insulation compared with CB.

Discussion

According to the results of distribution of demographics and LFN and HRV data, while the winter data (Site OD > Site ID) support our hypothesis that close proximity to wind turbines results in higher LFN exposure, the summer findings (Site ID > Site OD) of a higher LFN recorded with the wind turbines distant away imply a greater contribution to LFN from other sources indoors. Reviewing the differences between the sites in the two seasons showed that the use of fans indoor in hot weather was a potential source of LFN at Site ID. Summer in Taiwan is hot, and Site ID was equipped with fans for ventilation. Another possible source was human conversation. The voice of a typical adult male has a fundamental frequency from 85 to 180 Hz and that of a typical adult female has a fundamental frequency from 165 to 255 Hz[54].

To evaluate the contribution of these two potential sources, a follow-up assessment of the LFN at Site ID was performed. First, 15 min LFN measurements were taken for indoor background noise first without any fan or conversation, then they were taken with one turned-on household fan (medium-sized) roughly 3 m away from the NL-62, and finally they were taken with the ongoing conversation of five persons (three males and two females) at 2–5 m away from the NL-62. The LFN at a 1 min resolution was assessed. The results show that the average indoor background LFN was 32.5 ± 1.4 dB (L_{Aeq}) without fan use and conversation, 32.5 ± 1.4 dB (L_{Aeq}) with the fan turned on, and 44.1 ± 2.2 dB (L_{Aeq}) with ongoing conversation. As can be seen, with the fan turned on, the indoor LFN recorded was the same as the background LFN. In contrast, with ongoing conversation, the indoor LFN recorded was 11.6 dB (L_{Aeq}) higher than the background LFN. In other words, the summer findings

Seasons	Households	$L_{Aeq,5\text{-}min}$ indoor (dB) 24-h period	n	Daytime (7 am–7 pm)	Max	n	Evening (7 pm–10 pm)	Max	n	Nighttime (10 pm–7 am)	Max	n	Building material	[a]Distance (m)	[b]Habits of opening windows
(a) Indoor															
Summer	House 1	43.4 ± 3.1	472	44.2 ± 2.5[c]	49.6[c]	284	45.0 ± 4.1[c]	50.0[c]	64	40.8 ± 2.3[c]	48.5[c]	124	CN	124	x
	House 3	32.4 ± 5.1	364	33.8 ± 4.4	54.1[c]	270	32.6 ± 4.4	45.8[c]	25	26.5 ± 3.6	33.4	69	CB	308	x
	House 5	30.7 ± 3.0	404	32.1 ± 2.4	39.7[c]	253	28.6 ± 1.8	33.7[c]	36	28.2 ± 2.5	36.2[c]	115	CA	293	√
Winter	House 2	33.8 ± 8.1	513	39.4 ± 4.7[c]	51.8[c]	225	38.2 ± 4.9	48.3[c]	72	26.4 ± 5.4	47.9[c]	216	CN	277	x
	House 3	33.7 ± 8.3	813	34.4 ± 8.1	55.6[c]	385	34.7 ± 7.3	56.5[c]	104	32.5 ± 8.7	48.1[c]	324	CB	308	x
	House 4	37.9 ± 2.1	580	38.2 ± 2.8	52.2[c]	291	37.6 ± 0.6	40.0[c]	72	37.7 ± 0.8[c]	46.3[c]	216	CN	308	√
	House 5	30.7 ± 4.5	587	32.5 ± 3.8	49.0[c]	299	30.8 ± 2.9	39.7[c]	72	28.1 ± 4.5	42.2[c]	216	CA	293	x
	House 6	32.9 ± 6.3	600	36.4 ± 5.0	56.7[c]	312	33.7 ± 6.4	52.2[c]	72	27.6 ± 3.9	42.7[c]	216	CN	330	x
	House 7	37.7 ± 5.9	589	40.4 ± 5.3[c]	53.5[c]	302	41.1 ± 5.1[c]	53.8[c]	71	32.8 ± 3.1	44.3[c]	216	CN	328	x
(b) Outdoor															
Summer	House 1	50.0 ± 5.2	472	49.5 ± 5.0	55.3	284	50.2 ± 1.8	53.8	64	51.1 ± 6.5	56.0	124	CN	124	x
	House 3	38.2 ± 3.9	364	39.3 ± 2.8	47.8	270	38.0 ± 3.5	45.2	25	33.8 ± 4.6	45.6	69	CB	308	x
	House 5	44.4 ± 3.7	404	46.0 ± 2.9	54.5	253	41.8 ± 3.3	51.3	36	41.7 ± 3.5	51.5	115	CA	293	√
Winter	House 2	42.2 ± 6.1	513	46.4 ± 4.4	63.9	225	43.1 ± 3.4	54.7	72	37.5 ± 4.9	51.5	216	CN	277	x
	House 3	38.9 ± 4.8	273	41.2 ± 5.5	60.8	129	39.0 ± 3.7	47.8	36	36.2 ± 2.3	42.0	108	CB	308	x
	House 4	40.9 ± 5.6	595	44.2 ± 4.5	63.0	299	41.7 ± 3.8	61.7	80	36.0 ± 3.8	50.9	216	CN	308	√
	House 5	44.3 ± 4.5	587	46.8 ± 3.2	59.1	299	43.2 ± 3.4	52.6	72	41.2 ± 4.1	53.5	216	CA	293	x
	House 6	43.8 ± 4.1	585	45.8 ± 3.8	63.9	297	43.8 ± 4.3	64.1	72	41.1 ± 2.7	50.7	216	CN	330	x
	House 7	44.6 ± 4.0	589	46.8 ± 3.3	61.0	302	44.5 ± 3.5	58.9	71	41.7 ± 3.1	52.1	216	CN	328	x

Seasons	Households	$L_{Aeq,5\text{-}min}$ indoor (dB) 24-h period	n	Daytime (7 am–7 pm)	n	Evening (7 pm–10 pm)	n	Nighttime (10 pm–7 am)	n	Building material	[b]Habits of opening windows
(c) Indoor–outdoor											
Summer	House 1	6.6 ± 5.4	472	5.4 ± 4.6	284	5.2 ± 3.3	64	10.3 ± 6.2	124	CN	x
	House 3	5.8 ± 4.7	364	5.5 ± 4.7	270	5.4 ± 5.6	25	7.2 ± 3.8	69	CB	x
	House 5	13.7 ± 2.0	404	13.9 ± 1.9	253	13.2 ± 2.7	36	13.5 ± 2.1	115	CA	√
Winter	House 2	8.4 ± 6.7	513	6.9 ± 6.6	225	4.9 ± 6.3	72	11.1 ± 6.0	216	CN	x
	House 3	8.5 ± 4.1	273	7.8 ± 4.6	129	9.1 ± 3.6	36	9.0 ± 3.3	108	CB	x
	House 4	2.8 ± 5.0	579	5.8 ± 4.7	292	3.6 ± 2.7	72	1.7 ± 3.8	216	CN	√
	House 5	13.7 ± 3.9	586	14.4 ± 2.7	298	12.3 ± 3.3	72	13.1 ± 5.2	216	CA	x
	House 6	11.2 ± 3.9	585	9.8 ± 3.5	297	10.1 ± 5.5	72	13.5 ± 2.5	216	CN	x
	House 7	6.9 ± 4.1	589	6.4 ± 4.7	302	3.4 ± 4.2	71	8.8 ± 1.3	216	CN	x

Table 3. $L_{Aeq,5\text{-}min}$ LFN (dB, L_{Aeq}) measured at different households (a) indoors, (b) outdoors, and (c) outdoors minus indoors. *CN* concrete, *CB* concrete + brick, *CA* concrete + airtight windows. [a]Distance from the nearest wind turbine (m). [b]Habits of opening windows: √: fully open; x: slightly open or fully closed. [c]LFN exposure levels exceeding the respective standards designated by the Taiwan EPA.

(Site ID > Site OD) of the LFN recorded indoors surpassing that of the LFN recorded outdoors with wind turbines nearby can be attributed to the ongoing conversation indoors at the activity center.

Recio et al. (2016) indicated that exposure to repetitive noise may reduce emotional overload, but at the cost of increasing the allostatic load[26]. Therefore, the risk of adverse health outcomes may increase due to serious physiological alterations. In addition to decreasing the HRV, repetitive exposure to noise may induce the systemic inflammation and oxidative stress due to SAM and HPA overactivation. Moreover, systemic inflammation and oxidative stress may also cause autonomic imbalance[55], which affects HRV. The findings of the impacts of LFN exposure on HRV in our study are consistent with previous observations of reduced HRV due to LFN exposure in the US[27]. In a study on 10 healthy males, SDNN was reduced by 16% (95% CI: 6.1–26%) during 40 min LFN exposure as compared with no noise exposure. As stated above, few studies have assessed the impacts of LFN on HRV. With the increasing emphasis on renewable energy, a growing trend of more turbines being built for wind power can be expected. Hence, it is both timely and necessary to conduct more assessments on the potential health impacts of LFN generated by wind turbines.

In addition to LFN, studies have also indicated the possible effect of environmental noise on HRV. For 110 German adults exposed to daytime noise, the SDNN reduced by 0.67% for a 5 dBA increase when $L_{eq} \geq 65$ dBA[56]. Another study also showed a decrease from 17.42 to 17.7 ms for a 10 dBA increase above the background noise (45 dBA) in forty college-going male volunteers exposed to traffic noise[57]; the SDNN reduction was roughly 0.2%

per 1 dBA. Additionally, an SDNN reduction was observed for another important environment factor, $PM_{2.5}$. A significant decrease in SDNN (0.51%; 95% CI: 0.01–1.01%) was associated with a 10 μg/m^3 increase in $PM_{2.5}$ for Japanese patients aged 20–90 years[58]. A meta-analysis of 33 panel studies in North America, Asia, and Europe showed that a 0.92% reduction in SDNN was observed for a 10 μg/m^3 increase in short-term $PM_{2.5}$ exposure[59]. Wang et al. showed that 0.39% (95% CI: − 0.72%, − 0.06%) and 0.92% (95% CI: − 2.14%, 0.31%) reductions were observed for short-term and long-term exposures to a 10 μg/m^3 increase in $PM_{2.5}$, respectively, for adults aged above 55 years old[60]. In addition to this, SDNN was decreased from 54.7 to 39.6% with an increase in ambient temperatures from 17 to 38 °C (reduced by 0.72% per 1 °C) in 28 healthy young subjects[61]. In comparison, we found that SDNN reduction (0.43% per 1 dB) due to LFN from wind turbines was slightly higher than the reduction in traffic noise exposure > 65 dBA (0.13% per 1 dB), in a similar range or slightly lower than those with a 10 μg/m^3 increase in $PM_{2.5}$ exposure (0.39 to 0.92%) and slightly lower than those with ambient temperatures (0.72% per 1 °C). In short, the impact of LFN from wind turbines on HRV was higher than that from traffic noise and lower than that from $PM_{2.5}$ and ambient temperature.

The results of the impacts of LFN exposure on HRV also imply the absence or minimal lag effect of LFN on SDNN. During field monitoring, the subjects were shuttled between Site OD (high LFN exposure) and Site ID (low LFN exposure). Should there be a lag effect, their differences in LFN would be small, and the impact of LFN on SDNN would be insignificant, resulting in similar SDNNs at both sites. Nevertheless, the field monitoring results indicated a significant reduction in SDNN at Site ID (55.8 ms in summer and 64.2 ms in winter) compared to those at Site OD (65.3 ms in summer and 68.8 ms in winter). Hence, there was either no or a negligible lag effect. This observation was consistent with the results of a study conducted in Germany that showed that during routine activities, a 5 dB increase in $L_{Aeq} \geq 65$ dB (20–20 k Hz) was not associated with lagged SDNN change[56].

Besides LFN, wind speed is the only environmental variable with a significant impact on SDNN and LF/HF, but with opposing trends of changes (Table 2). In this study, wind speed and temperature were environmental variables adjusted in the GAMM of LFN on SDNN and LH/HF. The exact mechanism by which these variables impact the two HRV indicators remains to be explored.

The SDNN decreased with increasing age but did not reach statistical significance in our work. In the literature, studies have found a significant association of age with SDNN. For example, Kim and Woo found that SDNN significantly decreased with increasing age in 2748 males and 735 females in Korea[62]. Voss et al. also indicated an inverse association of age with SDNN for 1906 Germans aged 25–74 years[63]. Furthermore, population studies in the Netherlands found that SDNN decreased continuously from birth to old age for 28,827 participants with ages ranging from 11 days to 91 years[64]. In addition, as seen in Table 2, female subjects had a higher SDNN than male subjects, again not reaching statistical significance. Previous studies have also indicated that female subjects had a significantly higher SDNN than male subjects[62,64]. Our study results showed a trend of increased association of SDNN and age and higher SDNN in females, consistent with the results of previous studies. Nevertheless, the sample size in this work may be the reason for the statistical insignificance of these results.

One of the concerns of this study is the sample size. We have to emphasize that the objective of this study was to evaluate relationships between the LFN and HRV, which may be affected by many factors. There were some procedures for controlling these factors and increasing the sample size. First, the subjects had to complete the questionnaires and time-activity dairies to collect the information about these factors. Next, we had designed the conditions for indoor and outdoor environments, and we also controlled the subjects' activities in the field to control the impacts of environmental and activity factors on HRV. We also used the repeated measure design to increase the sample size. There were some challenges in field recruitment such as the limited number of residents in the studied community. In addition, the duration and funding of the study and the compliance of residents may also have affected the sample size. According to the above reasons, it was difficult to estimate the sample size before recruitment. Therefore, we tried to recruit as many subjects as possible in the field and tried to control the confounding factors for HRV. Moreover, we used the GAMM to assess the relationships between the LFN and HRV. The GAMM can control the subject variability with the random effect. We tried to increase the statistical power using the above procedures to determine whether the relationships between the LFN and HRV were significant. Based on our results, an increase in LFN was associated with a decrease in HRV.

Compared to the results of LFN exposure in residential households, previous studies have reported wind turbine LFN of 15–45 dB indoors in residences in Australia situated 870–3100 m from wind turbines[35], and indoor LFN levels of 0–10 dB during wind turbine operational periods for residences situated 1500 m from wind turbines in Australia[65]. In comparison, the maximum indoor LFN exposure during a 24-h period (43.4 dB) in our monitoring was similar to that reported (45 dB) by Hansen et al.[35] and higher than that (10 dB) reported by Evans et al.[65].

Our results also confirmed that these residents indeed were exposed to similar LFN levels as in the field campaign at the site OD. Therefore, HRV impacts from the LFN exposure evaluated in the field campaigns could be found in the daily lives of these residents. Hansen et al. and Evans et al. also reported that the LFN exposure levels from wind turbines for outdoor measurements were 25–40 dB and 21–25 dB, respectively[35,65]. Our monitoring of outdoor LFN exposure (38.2–50.0 dB) was higher than their results. The seven households in this study were located closer (124–330 m) to the turbines than the households in Hansen et al. (870–3100 m)[35] and Evans et al. (1500 m) were[65].

Table 3a also shows that the indoor LFN exposure levels (dB, L_{Aeq}) in most households were higher in the daytime than in the evening and nighttime. The higher LFN exposure level in the daytime could be attributed to other sources of background noise in addition to turbine-generated noise, while the LFN at nighttime presumably came mainly from wind turbines. House 1 recorded the highest mean and maximum nighttime LFN exposure (40.8 and 48.5 dB (L_{Aeq}), respectively), attributed to its close proximity to the wind turbines. According to the Guidelines for Community Noise[66], for a good night's sleep the equivalent sound level should not exceed 30 dB (L_{Aeq}) for continuous background noise. However, the average indoor LFN levels at night in Houses 1,

3, 4, and 7 were above 30 dB (L_{Aeq}), and 100% of the 5 min nighttime observations recorded in Houses 1 and 4 exceeded 30 dB (L_{Aeq}), implying that turbine-generated LFN may affect residents' quality of sleep at night in these households.

Taiwan's EPA designates different noise standards in residential areas for different times of day: daytime (39 dB, L_{Aeq}, 7 am to 7 pm), evening (39 dB, L_{Aeq}, 7 pm to 10 pm), and nighttime (36 dB, L_{Aeq}, 10 pm to 7 am)[32]. According to these guidelines, House 1 (daytime, evening, and nighttime), House 2 (daytime), House 4 (nighttime), and House 7 (daytime and evening) had LFN exposure levels exceeding the respective standards designated by the Taiwan EPA (Table 3a). Among these residences monitored, residents at House 1 had higher LFN exposures from wind turbines round the clock, indicating that they exceeded the LFN standards of Taiwan's EPA 99.6%, 89.1%, and 96.8% of the time for the daytime, evening, and nighttime, respectively. The impacts of distance, building materials, and having windows open/closed on the LFN can be illustrated by our cases, as briefly discussed below. The significant influence of distance from turbines on the indoor LFN exposure level is best illustrated by House 1. With the shortest distance from wind turbines, House 1 had the highest mean LFN exposure, both indoors and outdoors, during the 24-h period, with its indoor LFN exposure ranging from 40.8 to 45.0 dB (L_{Aeq}) and the maximum level reaching 50 dB (L_{Aeq}) in the evening. However, House 6, the farthest (330 m) among the seven households monitored, did not record the lowest mean LFN exposure. Instead, the lowest LFN exposure of 30.7 dB (L_{Aeq}) in both seasons was recorded inside House 5 (concrete with airtight windows (CA)), the only residence with airtight windows installed. Windows serve as sound attenuation[67]. Although the resident of House 5 indicated a habit of keeping windows fully open in the summer (Table 3), the windows were actually closed during the monitoring period according to our observation. Moreover, House 5 had only one resident, and the windows were kept closed when the house was empty. A single-member household with less ongoing conversation would imply the absence or negligible contribution of this indoor LFN source (unlike the situation at Site ID). Moreover, keeping airtight windows closed most of the time contributes to low sound transmission. The soundproofing effectiveness of airtight windows is evidenced by the largest indoor–outdoor difference in LFN of 13.7 dB (L_{Aeq}) recorded for House 5 in both seasons (Table 3c).

Houses 3 and 4 were located at equal distances (308 m) from the nearest turbine, but their average indoor LFN exposure differed by 4 dB (33.7 dB (L_{Aeq}) and 37.9 dB (L_{Aeq}), respectively (Table 3a). The results indicated that though it had been built with concrete (CN), House 4 had a higher indoor LFN recorded, which can be attributed to the fully open windows, resulting in poorer sound insulation compared with House 3 with its fully closed windows. Therefore, the impacts of opening the windows on the indoor LFN were more significant than those of building materials in this case.

The impacts of building materials on LFN were not a focus of our study. However, the indoor–outdoor LFN difference in seven households presented certain indications of their impacts. In summary, distance from turbines, building materials used, types of windows installed, and whether they are open or closed all had impacts on the indoor LFN levels in our study.

Recommendations and study limitations. The present results show the adverse impact of LFN exposure on HRV. For public health protection, there should be regulations on the requisite distances of wind turbines from residential communities. In Taiwan, wind farms are owned by large corporations, and distance regulations would prevent these operators from reaping benefits at the expense of nearby residents suffering from long-term LFN disturbance and adverse health impacts. In order to reduce LFN transport from outdoors to indoors, we recommend that the windows should be kept closed, especially at nighttime because LFN is most noticeable at night. In addition, airtight windows are good for sound insulation. Therefore, we recommend that residences in close proximity to wind turbines should be equipped with airtight windows. As far as we know, a small number of wind turbine firms provided certain funding to install the airtight windows for residents living nearby. We suggest that this funding should be required by governmental agencies.

This study has some limitations. Firstly, at Site ID for the households monitored, indoor LFN was caused by wind turbines, but there may also exist other indoor LFN sources, such as indoor ventilation devices, ongoing conversations, or television, which have not been thoroughly explored. Secondly, our sample size was small due to difficulties in recruitment. Nevertheless, the findings obtained from the 30 subjects still demonstrated the impacts of LFN on HRV changes. Thirdly, the average analyzable wear time (86.2%) was lower than that (93.6%) found in previous research[41]. Nevertheless, data loss occurred randomly and did not undermine the validity of the present findings. Fourthly, except for LFN sources, the psychological stress from other sources was not assessed in this study, which may affect HRV. However, if the psychological stress from other sources and LFN did not always concurrently affect the HRV, the psychological stress from other sources would not affect the coefficients of LFN. Finally, air pollutants such as $PM_{2.5}$ levels were not measured in this study. Exposure to $PM_{2.5}$ may cause a reduced HRV. Previous study found that evaluated $PM_{2.5}$ exposure and noise exposure were both associated with changes in HRV[68]. However, they only measured the levels of noise rather than the frequency of noise. The interaction of LFN with $PM_{2.5}$ should be evaluated in future studies.

Conclusion

LFN from wind turbines is potentially annoying to residents living nearby and affects human health. This study assessed the response of HRV indicators (SDNN and LF/HF) to LFN exposure and evaluated the LFN exposure inside households located near wind turbines. The results showed the association of changes in HRV with LFN exposure and an SDNN reduction of 0.43% with an increase of 1 dB (L_{Aeq}) in LFN. The households' average LFN levels were 34.8 ± 6.9 and 43.4 ± 5.7 dB for indoors and outdoors, respectively. In addition, the average indoor LFN levels at nighttime in four of the seven households monitored were above 30 dB (L_{Aeq}), the threshold for good sleep quality. Taiwan has a high population density, and wind farms have been set up near residential

communities. In view of the adverse health impacts of exposure to turbine-generated LFN, it is recommended that the government set regulations on the requisite distances of wind turbines from residences, for houses near wind turbines to be equipped with airtight windows for sound insulation, and for residents living in close proximity to wind turbines to have their windows closed most of the time to reduce LFN transmission.

Received: 9 March 2021; Accepted: 17 August 2021
Published online: 08 September 2021

References

1. Minnesota Department of Health (MDH). *Public health impacts of wind turbines*. St. Paul (MN) (2009).
2. Møller, H. & Pedersen, C. S_Low-frequency noise from large wind turbines. *J. Acoust. Soc. Am.* **129**(6), 3727 (2011).
3. Bolin, K., Bluhm, G., Eriksson, G. & Nilsson, M. E. Infrasound and low frequency noise from wind turbines: exposure and health effects. *Environ. Res. Lett.* **6**, 1–6 (2011).
4. Schmidt, J. H. & Klokker, M. Health effects related to wind turbine noise exposure: A systematic review. *PLoS ONE* **9**(12), e114183 (2014).
5. Hansen, C. & Hansen, K. Recent advances in wind turbine noise research. *Acoustics* **2**, 171–206 (2020).
6. Alves-Pereira, M. & Castelo Branco, N. A. A. Vibroacoustic disease: Biological effects of infrasound and low-frequency noise explained by mechanotransduction cellular signaling. *Prog. Biophys. Mol. Biol.* **93**, 256–279 (2007).
7. Pedersen, C. S., Møller, H. & Waye, K. P. A detailed study of low-frequency noise complaints. *J. Low Freq. Noise Vibrat. Active Control.* **27**, 1–33 (2008).
8. Pierpont, N. *Wind Turbine Syndrome* (K-Selected Books, 2009).
9. Salt, A. N. & Hullar, T. E. Responses of the ear to low frequency sounds, infrasound and wind turbines. *Hear Res.* **268**, 12–21 (2010).
10. Farboud, A., Crunkhorn, R. & Trinidade, A. "Wind turbine syndrome": Fact or fiction?. *J. Laryngol. Otol.* **127**(3), 222–226 (2013).
11. Onakpoya, I. J., O'sullivan, J., Thompson, M. J. & Heneghan, C. J. The effect of wind turbine noise on sleep and quality of life: A systematic review and meta-analysis of observational studies. *Environ. Int.* **82**, 1–9 (2015).
12. Abbasi, M. *et al.* Assessment of noise effects of wind turbine on the general health of staff at wind farm of Manjil. *Iran. J. Low Freq. Noise Vib. Act. Control* **35**, 91–98 (2016).
13. Morsing, J. A. *et al.* Wind turbine noise and sleep: Pilot studies on the influence of noise characteristics. *Int. J. Environ. Res. Public Health* **15**(11), 2573 (2018).
14. Ishitake, T. Wind turbine noise and health effects. *Nihon Eiseigaku Zasshi* **73**, 298–304 (2018).
15. Pohl, J., Gabriel, J. & Hübner, G. Understanding stress effects of wind turbine noise—The integrated approach. *Energy Policy* **112**, 119–128 (2018).
16. Poulsen, A. H. *et al.* Impact of long-term exposure to wind turbine noise on redemption of sleep medication and antidepressants: A nationwide cohort study. *Environ. Heal. Perspect.* **127**(3), 37005 (2019).
17. Hansen, K. L., Nguyen, P., Zajamšek, B., Catcheside, P. & Hansen, C. H. Prevalence of wind farm amplitude modulation at long-range residential locations. *J. Sound Vib.* **455**, 136–149 (2019).
18. Alves, J. A., Paiva, F. N., Silva, L. T. & Remoaldo, P. Low-frequency noise and its main effects on human health—A review of the literature between 2016 and 2019. *Appl. Sci.* **10**, 5205 (2020).
19. Lubner, R. J. *et al.* Review of audiovestibular symptoms following exposure to acoustic and electromagnetic energy outside conventional human hearing. *Front. Neurol.* **11**, 234 (2020).
20. Branco, N. A. & Alves-Pereira, M. Vibroacoustic disease. *Noise Health* **6**(23), 3–20 (2004).
21. Alves-Pereira, M. & Branco, N. C. In-home wind turbine noise is conducive to vibroacoustic disease. In *Proceedings of the Second International Meeting on Wind Turbine Noise, Lyon, France*, pp. 20–21 (2007).
22. Kleiger, R. E., Miller, J. P., Bigger, J. T. & Moss, A. J. Decreased heart rate variability and its association with increased mortality after acute myocardial infarction. *Am. J. Cardiol.* **59**(4), 256–262 (1987).
23. Tsuji, H. *et al.* Impact of reduced heart rate variability on risk for cardiac events—The Framingham Heart Study. *Circulation* **94**(11), 2850–2855 (1996).
24. Shaffer, F. & Ginsberg, J. P. An overview of heart rate variability metrics and norms. *Front. Public Health* **5**, 258 (2017).
25. Thayer, J. F., Yamamoto, S. S. & Brosschot, J. F. The relationship of autonomic imbalance, heart rate variability and cardiovascular disease risk factors. *Int. J. Cardiol.* **141**, 122–131 (2010).
26. Recio, A., Linares, C., Banegas, J. R. & Díaz, J. Road traffic noise effects on cardiovascular, respiratory, and metabolic health: An integrative model of biological mechanisms. *Environ. Res.* **146**, 359–370 (2016).
27. Walker, E. D., Brammer, A., Cherniack, M. G., Laden, F. & Cavallari, J. M. Cardiovascular and stress responses to short-term noise exposures-A panel study in healthy males. *Environ. Res.* **150**, 391–397 (2016).
28. Antila, M. Wind turbine excess noise evaluation. in *Presentation EWEA Technology Workshop Wind Turbine Sound*, VTT Technical Research Centre of Finland, 9–10 December 2014, Malmö, Sweden (2014).
29. Energy Technology Support Unit (ETSU). The Assessment and Rating of Noise from Wind Farms. Final Report, ETSU-R-97, The Working Group on Noise from Wind Turbines, September (1996).
30. United States Environmental Protection Agency (USEPA). Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety. 550/9- 74-004. Washington, D.C.: Office of Noise Abatement and Control. March (1974).
31. United States Environmental Protection Agency (USEPA). EPA Identifies Noise Levels Affecting Health and Welfare, EPA press release - April 2, 1974. Web site https://archive.epa.gov/epa/aboutepa/epa-identifies-noise-levels-affecting-health-and-welfare.html (1974)
32. Taiwan Environmental Protection Administration (Taiwan EPA). *The History of Noise Control, Taipei, Taiwan* (2017) **(in Chinese)**.
33. Pantazopoulou, P. Wind turbine noise measurements and abatement methods. In *Wind Power Generation and Wind Turbine Design* (ed. Tong, W.) 641–660 (WIT Press, 2010).
34. Evans, T. & Cooper, J. Influence of wind direction on noise emission and propagation from wind turbines. In *Proceedings of Acoustics 2012—Fremantle, 21–23 November 2012, Fremantle* (2012).
35. Hansen, K. L., Hansen, C. H. & Zajamsek, B. Outdoor to indoor reduction of wind farm noise for rural residences. *Build. Environ.* **94**, 764–772 (2015).
36. Hansen, C. H. & Goelzer, B. I. F. Engineering noise control. In *Occupational Exposure to Noise: Evaluation, Prevention and Control* (eds. Goelzer, B.I.F., Hansen, C.H., Sehrndt, G.A). Chap. 10 (World Health Organization, 2001).
37. Lindkvist, P. *Lågfrekvent buller från vindkraftverk: Mätning och modellering i bostadsrum med avseende påljudutbredning och ljudisolering. (Low-Frequency Noise from Wind Turbines: Measuring and Modeling in Living Rooms with Respect to Sound Propagation and Sound Insulation)*. Vol. Masters (KTH Royal Institute of Technology, 2010) (2010) **(in Swedish)**.
38. Søndergaard B, Hoffmeyer D & Plovsing B. Low frequency noise from large wind turbines. Proc. Second International Meeting on Wind Turbines Noise, Lyon (2007).

39. Sound Level Meter NL-62. Instruction Manual. Japan: Rion, 3-20-41 Higashimotomachi, Kokubunji, Tokyo 185–8533, Japan (2012).
40. Karaoguz, M. R. *et al.* The quality of ECG data acquisition, and diagnostic performance of a novel adhesive patch for ambulatory cardiac rhythm monitoring in arrhythmia detection. *J. Electrocardiol.* **54**, 28–35 (2019).
41. Lung, S. C. C. *et al.* Panel study using novel sensing devices to assess associations of $PM_{2.5}$ with heart rate variability and exposure sources. *J. Exp. Sci. Environ. Epidemiol.* **30**, 937–948 (2020).
42. Force, T. Standards of measurement, physiological interpretation, and clinical use. *Eur. Heart J.* **17**, 354–381 (1996).
43. Tang, C. S. *et al.* Impacts of in-cabin exposure to size-fractionated particulate matters and carbon monoxide on changes in heart rate variability for healthy public transit commuters. *Atmosphere* **10**(7), 409 (2019).
44. Tsou, M. C. M. *et al.* A community-based study on associations between PM2.5 and PM1 exposure and heart rate variability using wearable low-cost sensing devices. *Environ. Pollut* **277**, 116761 (2021).
45. Xu, M. M. *et al.* Relationship between ambient fine particles and ventricular repolarization changes and heart rate variability of elderly people with heart disease in Beijing, China. *Biomed. Environ. Sci.* **26**(8), 629–637 (2013).
46. Lucreziotti, S. *et al.* Five-minute recording of heart rate variability in severe chronic heart failure: Correlates with right ventricular function and prognostic implications. *Am. Heart J.* **139**, 1088–1095 (2000).
47. Goldberger, J. J., Challapalli, S., Tung, R., Parker, M. A. & Kadish, A. H. Relationship of heart rate variability to parasympathetic effect. *Circulation* **103**, 1977–1983 (2001).
48. Slaap, B. R., Boshuisen, M. L., van Roon, A. M. & den Boer, J. A. Heart rate variability as predictor of nonresponse to mirtazapine in panic disorder: A preliminary study. *Int. Clin. Psychopharmacol.* **17**, 69–74 (2002).
49. Min, K. B. *et al.* Is 5-minute heart rate variability a useful measure for monitoring the autonomic nervous system of workers?. *Int. Heart J.* **49**(2), 175–181 (2008).
50. Migliaro, E. R. & Contreras, P. Heart rate variability: Short-term studies are as useful as holter to differentiate diabetic patients from healthy subjects. *Ann. Noninvasive Electrocardiol.* **8**, 313–320 (2003).
51. Ministry of Health and Welfare Taiwan. https://www.hpa.gov.tw/Pages/Detail.aspx?nodeid=542&pid=705. (2011).
52. Thorsson, P. *et al.* Low-frequency outdoor–indoor noise level difference for wind turbine assessment. *J. Acoust. Soc. Am.* **143**(3), 206–211 (2018).
53. Pothineni, N. V., Shirazi, L. F. & Mehta, J. L. Gender differences in autonomic control of the cardiovascular system. *Curr. Pharm. Des.* **22**(25), 3829–3834 (2016).
54. Titze, I. R. *Principles of Voice Production*. 188. (Prentice Hall (currently published by NCVS.org), 1994).
55. Brook, R. D. *et al.* Particulate matter air pollution and cardiovascular disease: An update to the scientific statement from the American Heart Association. *Circulation* **121**(21), 2331–2378 (2010).
56. Kraus, U. *et al.* Individual daytime noise exposure during routine activities and heart rate variability in adults: A repeated measures study. *Environ. Health Perspect.* **121**, 607–612 (2013).
57. Sim, C. S. *et al.* The effects of different noise types on heart rate variability in men. *Yonsei Med. J.* **56**, 235–243 (2015).
58. Paoin, K. *et al.* Association between $PM_{2.5}$ exposure and heart rate variability for the patients with cardiac problems in Japan. *Air Qual. Atmos. Health* **13**, 339–347 (2020).
59. Niu, Z. *et al.* Acute effect of ambient fine particulate matter on heart rate variability: An updated systematic review and meta-analysis of panel studies. *Environ. Health Prevent. Med.* **25**(77), 13 (2020).
60. Wang, F. *et al.* The relationship between exposure to $PM_{2.5}$ and heart rate variability in older adults: A systematic review and meta-analysis. *Chemosphere* **261**, 127635 (2020).
61. Shin, H. Ambient temperature effect on pulse rate variability as an alternative to heart rate variability in young adult. *J. Clin. Monit. Comput.* **30**, 939–948 (2016).
62. Kim, G. M. & Woo, J. M. Determinants for heart rate variability in a normal Korean population. *J. Korean Med. Sci.* **26**, 1293–1298 (2011).
63. Voss, A., Schroeder, R., Heitmann, A., Peters, A. & Perz, S. Short-term heart rate variability-influence of gender and age in healthy subjects. *PLoS ONE* **10**(3), 0118308 (2015).
64. Van den Berg, M. E. *et al.* Normal values of corrected heart-rate variability in 10-second electrocardiograms for all ages. *Front. Physiol.* **9**(424), 1–9 (2018).
65. Evans, T., Cooper, J. & Lenchine, V. *Low Frequency Noise Near Wind Farms and in Other Environments*. South Australian Environment Protection Authority and Resonate Acoustics, http://www.epa.sa.gov.au/xstd_files/Noise/Report/low_frequency.pdf. (2013).
66. Berglund, B., Lindvall, T. & Schwela, D. H. *Guidelines for Community Noise* (World Health Organization, 1999).
67. Park, H. K. & Kim, H. Acoustic insulation performance of improved airtight windows. *Constr. Build. Mater.* **93**, 542–550 (2015).
68. Huang, J. *et al.* The impacts of short-term exposure to noise and traffic-related air pollution on heart rate variability in young healthy adults. *J. Expo Sci. Environ. Epidemiol.* **23**, 559–564 (2013).
69. *Google Earth Pro 7.3.2.5776 (beta). (September 19, 2020). Hsinchu, ON Taiwan. 24°55'12"N, 120°58' 26"E, Eye alt 16 mi.* Accessed 1 Dec 2020.

Acknowledgements

The authors acknowledge the financial support from the Ministry of Science and Technology, Taiwan, under the project entitled "Taiwan's Deep Decarbonization Pathways toward a Sustainable Society", AS-KPQ-106-DDPP. The contents of this paper are solely the responsibility of the authors and do not represent the official views of the aforementioned institutes and funding agencies.

Author contributions

C.H.C.: Conceptualization, Validation, Formal analysis, Investigation, Data Curation, Writing-Original Draft. S.C.C.L.: Validation, Resources, Writing-Review & Editing, Supervision, Project administration, Funding acquisition. N.C.: Formal analysis, Investigation, Data Curation. J.S.H.: Conceptualization, Writing—Review & Editing. All authors reviewed the manuscript. M.C.M.T.: Writing—Review & Editing.

Competing interests

The authors declare no competing interests.

Additional information

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1038/s41598-021-97107-8.

Correspondence and requests for materials should be addressed to S.-C.C.L.

PROCEEDINGS of the
23rd International Congress on Acoustics

9 to 13 September 2019 in Aachen, Germany

Low freq. noise

Sleep disorders

Epidemiological study on long-term health effects of low-frequency noise produced by wind power stations in Japan

Tatsuya ISHITAKE[1]; Yoshitaka MORIMATSU[1]; Kunio HARA[2]

[1] Kurume University, School of Medicine, Japan

[2] University of Occupational and Environmental Health, School of Health Science, Japan

ABSTRACT

We investigated whether long-term exposure to wind turbine noise (WTN) including low-frequency noise generated by wind power facilities is a risk factor of sleep disorders. We performed an epidemiological study of living environment and health effects, surveying 9,000 residents (≥20 years) living in areas with operational wind power facilities. Sleep disorders were assessed using the Athens Insomnia Scale. To assess environmental noise in residential areas near the wind turbines, low-frequency sound exposure levels were measured at 50 community centers of the town. Multiple logistic regression analysis was used for evaluation of a risk factor for several noise exposure indices. Significant relationships between the distance from the nearest WT to dwellings and hearing, annoyance, sleep disorders were observed. By multiple logistic analysis the prevalence rate of sleep disorders was significantly higher for residents who reported subjectively hearing noise being than for those who did not. Moreover, the reported prevalence rate of sleep disorders was significantly higher in residents living at a distance of ≤1,500 m from the nearest wind turbine compared to that for residents living at a distance ≥2,000 m. The attitudes of residents towards wind power facilities and sensitivity to noise strongly affected their responses regarding sleep disorder prevalence.

Keywords: audible noise, epidemiology, infrasound, low-frequency noise, sleep disorder, wind turbine noise

1. INTRODUCTION

The effect of the noise of wind power generation facilities on health is a growing concern. This is especially true regarding infrasound, defined as sound lower in frequency than 20 Hz. Plans for new wind power generation facilities have had to be changed in some cases in Japan due to the health concerns of local residents.

Multiple cross-sectional epidemiological studies have shown a strong relationship between annoyance and living in close proximity to wind turbines. It has been reported that individual factors such as the visual impact of wind turbines, attitudes towards wind turbine installation, and economic benefits are more strongly related to the presence or absence of annoyance than the actual noise of wind turbines (1).

Other studies have reported that rather than focusing on the noise of wind turbines, more attention should be paid to cofounding factors such as attitudes toward wind power generation, impact on scenic views, economic benefits, visibility of wind turbines, sensitivity to sound, and concerns about health (2).

Previous epidemiological studies have frequently reported that audible noise generated by wind turbines is significantly associated with annoyance and sleep disorder (3, 4). On the other hand, no clear relationship has been reported thus far between infrasound and effects on health (5). Furthermore, most epidemiological studies have used a cross-sectional design, and therefore cannot confirm a causal relationship between wind turbine noise and health effects.

The present cross-sectional epidemiological study targeted local residents in Japan where wind power generation facilities were already active, and sought to determine how exposure to infrasound and noise from these facilities in Japan affects health, specifically the presence of a sleep disorder.

[1] tishitak@med.kurume-u.ac.jp

I-19

2. METHODS

The target area is Nagashima-cho, Izumi-gun on Nagashima Island, located in the northern part of Kagoshima prefecture. Its population is 10,400. The island is longer in the north-south direction, with an area of approximately 110 km^2. The middle of the island is mountainous, and ports are located around the island perimeter. Wind power generation facilities (output 2.4 MW x 21 stations, wind speed rate 12.5 m/s) were introduced in August 2008, in the middle of the island. Most residences are located at least 1 km from the closest wind turbine, and there are no residences within 500 m of a wind turbine.

We conducted this survey by distributing a questionnaire to residents of Nagashima-cho aged 20 years and older (approximately 9,000 people) in December 2014. The survey was distributed to each household via a circulation board, a traditional method of disseminating information in Japanese neighborhoods, in cooperation with 57 directors of public city halls (local cultural centers, one in each school district, providing recreation and learning for local residents). Participants returned the questionnaire using a prepaid return envelope.

The questionnaire contained items addressing family structure, family residence, living arrangement, lifestyle, social and economic factors, health conditions, level of annoyance with wind turbine noise, attitude towards installation of wind power generation facilities and reaction to their visual impact, as well as basic personal attributes (gender, age, height and weight). The presence of a sleep disorder was evaluated using the Athens Insomnia Scale (AIS) (Japanese version). The AIS was developed in 2000 by the World Health organization (WHO) based on the 10^{th} version of the International Statistical Classification of Diseases and Related Health Problems (ICD-10), and its Japanese version was created in 2013. The first five items of the questionnaire pertain to difficulty in sleep induction, awaking during the night, early morning awakening, sleep duration and quality of sleep. The remaining three items consist of questions related to sleepiness, sense of well-being and the level of active functioning during the day. Each response uses a 4-point Likert-type scale (0 = no problem, 1 = minor problem, 3 = considerable problem, 4 = serious problem), and the total is calculated (range 0–32). A score of more than 6 points indicates the presence of a sleep disorder.

The distance from each household residence to the nearest wind turbine was defined using a proxy, namely the distance from the wind turbine to the public city hall of the school district in which the residence was located. The relationship between sleep disorders and noise was reviewed using the following four noise-related indicators: 1) whether or not the noise was consciously audible, 2) horizontal distance from the wind turbine to the district public city hall, 3) wind turbine noise at night (the A-weighted equivalent sound level (L_{Aeq})) and 4) difference between wind turbine noise and background noise.

A summary of the measurement method is as follows. Research was conducted to determine the infrasound/noise attenuation curve over distance from the wind power generation facility. A broadband sound pressure level meter was used to measure the level of infrasound and noise at the public city hall of each school district. Since the measurement of infrasound is easily affected by wind, we covered a microphone with a two-layer wind-proof screen. Assessment of infrasound/noise exposure levels at the public city halls was conducted for 24 consecutive hours once per season in 2014, at 72 locations: these locations were inside 47 public city halls among 57 public city halls/meeting facilities in Nagashima-cho, mainly located in the center of the island. The A-weighted equivalent continuous sound level $L_{Aeq,10min}$ was calculated based on each hour of infrasound/noise was detected from the wind power generation facilities, then the mean energy was derived from the entire time range and the wind turbine A-weighted equivalent continuous sound level $L_{Aeq,WTN}$ was calculated at each measurement point. Regarding the total noise, the A-weighted equivalent continuous sound level for every hour and the sound pressure level of noise changes over time were calculated, then the sound pressure levels during daytime (6:00 to 22:00) and nighttime (22:00 to 6:00) were derived using the arithmetic mean for the percentile sound pressure levels and the mean energy for the A-weighted equivalent continuous sound levels.

Statistical analysis used the chi-squared test and multiple logistic regression analysis. Three models were evaluated using multiple logistic regression analysis: model 1, adjusted by gender and age; model 2, adjusted by the variables in model 1 as well as by three social factors, namely shift work, income and marital status; and model 3, adjusted by the variables in model 2 as well as by the attitude towards the visual impact of the wind turbines and the current attitude toward the original wind turbine installation. The distance from the residence to the wind turbine was divided into five categories: less than 1,000 m; between 1,000 and 1,500 m; between 1,500 and 2,000 m; between

2,000 and 5,000 m; and 5,000 m and above. There were 2,593 responses to the survey (collection rate 28.3%). Of these, 401 were disqualified due to missing gender or age (75 responses), missing city hall district (29 responses), and age 80 years old or older (287 responses). The final number of qualified survey responses was 2,192.

3. RESULTS

3.1 Participants characteristics and living arrangements

Table 1 shows the participants characteristics and living arrangements. The mean age was 58.1 years, and the gender ratio of males to females was 1.06. Regarding the most common living arrangements, 90.2% of participants lived with family and 82.3% had lived in the same residence for 10 years or more. The rates of smoking and drinking on an almost daily basis were 17.8% and 33.5%, respectively, with a significant difference between males and females. Approximately 40% agreed that "the wind turbine is visible from home." and approximately 15% agreed that "the sound of the wind turbine is audible from home." The mean distance from the closest wind turbine to each public city hall was approximately 3,000 m, and the minimum distance was 730 m. The mode of the distance category was 2,000 to 5,000 m, accounting for 56% of responses. The mode of the nighttime wind turbine noise level category was 20-50 dB.

Table 1 Basic characteristics of subject and environmental status

items	n(%)		
sex		male 1,126(51.4	female 1,066(48.6)
age	average year 58.1	58.3	57.9
marriage status			
spouse	1,671(77.0)		
bereavement	64 (7.5)		
separation	91 (4.2)		
single	245 (11.3)		
family constitution			
single life	202 (9.3)		
living with family	1,958(90.2)		
others	11 (0.5)		
residence number of years			
under 1 year	52 (2.4)		
1-3 years	105 (4.8)		
3-5 yeas	84 (3.9)		
5-10 years	145 (6.6)		
over 10 years	1,794(82.3)		
smoking status	total	male	female
no smoker	1,604(73.5)	610(54.3)	994(93.9)
smoker	389(17.8)	334(29.7)	55 (5.2)
ex-smoker	189 (8.7)	179(16.0)	10 (0.9)
alcohol drinking status	total	male	female
every day	731(33.5)	623(55.6)	108(10.2)
once a week	232(10.6)	133(11.9)	99 (9.3)
once a month	134 (6.1)	62 (5.5)	72 (6.8)
no drinking	1,083(49.7)	303(15.9)	780(73.7)
Can you see a wind turbine from one' s residence' s house			
yes	872 (41.5)		
no	1,228 (58.5)		
Can you hear a sound from wind turbine from one' s residence' s house			
yes	335 (15.6)		
no	1,813 (84.4)		
distance from the nearest wind turbine to one' s residence' s house			
	average 3,093m (min.730m, max.10,768m)		
<1,000m	87 (4.3)		
1,000-1,500m	187 (9.2)		
1,500-2,000m	364 (17.9)		
2,000-5,000m	1,148 (56.4)		
≥5,000m	248 (12.2)		
wind turbine noise at night (L_{Aeq})			
<20 dB	273 (14.3)		
20-25 dB	712 (37.4)		
25-30 dB	517 (27.1)		
30-35 dB	257 (13.4)		
35-40 dB	146 (7.7)		

3.2 Relationship between audible noise and distance to wind turbine and prevalence of sleep disorders

Figure 1 shows the proportion of participants who reported hearing the sound of wind power generation facilities at home, categorized by distance from their public city hall to the nearest wind turbine. For distances less than 1,000 m, 63% reported that the noise was audible, and this percentage decreased significantly with increasing distance. Even at distances of 5,000 m and over, 2% of respondents stated that the turbines were audible. Sleep disorder (AIS ≥ 6 points) was present in 26% (528 people) of participants, but this percentage was approximately 40% in those whose homes were less than 1,000 m from a wind turbine (Fig. 2). The frequency of sleep disorder decreased to 22% at a distance of 2000 m to 5000 m, but then increased to 30% at a distance of 5,000 and over. There was a statistically significant relationship between distance and sleep disorder frequency ($p < .001$).

Figure 1 The proportion of participants who reported hearing the sound of wind turbine by distance from the nearest wind turbine to residence's house

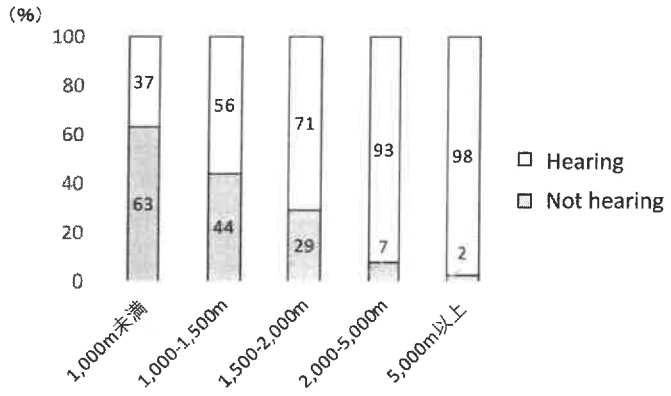
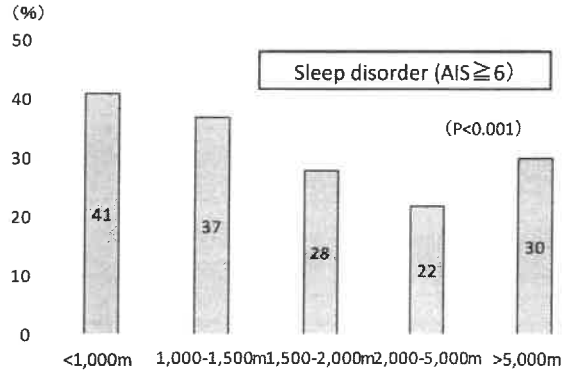


Figure 2 The prevalence of sleep disorder by distance from the nearest wind turbine to residence's house



3.3 Multiple logistic regression analysis

Multiple logistic regression analyses were performed with the presence of a sleep disorder as an independent variable, and the wind turbine noise indicator was modeled considering the following dependent variables: 1) whether or not wind turbine noise was consciously audible, 2) distance from the resident's public city hall to the wind turbine, 3) nighttime wind turbine noise (L_{Aeq}) and 4) difference between wind turbine noise and background noise. The results of this analysis are shown in Tables 2 to 5. In every model, participants who agreed that "wind turbine noise is consciously audible" had approximately twice the odds of having a sleep disorder as those who responded negatively, and this difference was statistically significant (Table 2). As for the impact of distance to the wind turbine, residents who lived within 1,500 m were approximately twice as likely to have a sleep disorder as those who lived at least 2,000 m away, indicating a statistically significant difference (Table 3). In terms of exposure to nighttime wind turbine noise (L_{Aeq}), those exposed to 35 dB or more had a 1.5-fold higher likelihood of having a sleep disorder than those exposed to the typical level of 20–25 dB, again a statistically significant difference (Table 4). Finally, regarding the difference between wind turbine noise and background noise, participants exposed to a difference of 5 dB or more had an approximately 1.6-fold higher likelihood of having a sleep disorder than those exposed to a difference of less than 5 dB, indicating a statistically significant impact (Table 5).

Table 2 The relationship between hearing a sound of wind turbine from residence's house and sleep disorder

			Odds ratio (95% confidence interval)					
	N	case (%)	model 1	p	model 2	p	model 3	p
Hearing a sound	1,713	397 (23.1)	1.00		1.00		1.00	
Not hearing a sound	320	131 (40.9)	2.28 (1.77–2.93)	<0.0001	2.15 (1.63–2.83)	<0.0001	1.89 (1.89–2.52)	<0.0001

model 1: adjustment with sex and age

model 2: adjustment with sex, age, marriage status, work with income and shift work

model 3: adjustment with sex, age, marriage status, work with income, shift work, attitude to wind turbine development and visual impact.

Table 3 The distance from wind turbine to one's residence and sleep disorder

			Odds ratio (95% confidence interval)					
	N	case (%)	model 1	p	model 2	p	model 3	p
Under 1,000 m	78	32 (41.3)	2.28 (1.50–3.89)	0.0004	2.36 (1.35–4.04)	0.0028	1.93 (1.08–3.38)	0.028
1,000 – 1,500 m	166	62 (37.4)	2.11 (1.49–2.98)	<0.0001	2.15 (1.63–2.83)	0.0003	1.91 (1.29–2.83)	0.0018
1,500 – 2,000 m	349	97 (27.8)	1.35 (1.02–1.79)	0.0034	1.32 (0.97–1.79)	0.0820	1.32 (0.96–1.80)	0.0859
2,000 – 5,000 m	1,079	235 (21.8)	1.00		1.00		1.00	
Over 5,,000 m	293	80 (27.3)	1.38 (1.02–1.85)	0.0377	1.25 (0.90–1.74)	0.1827	1.24 (0.88–1.73)	0.2134

model 1: adjustment with sex and age

model 2: adjustment with sex, age, marriage status, work with income and shift work

model 3: adjustment with sex, age, marriage status, work with income, shift work, attitude to wind turbine development and visual impact.

Table 4 Wind turbine noise at night (L_{Aeq}) and sleep disorder

			Odds ratio (95% confidence interval)					
	N	case (%)	model 1	p	model 2	p	model 3	p
<20 dBA	273	76 (27.8)	1.24 (0.90–1.70)	0.1880	1.20 (0.85–1.69)	0.2944	1.21 (0.85–1.71)	0.2884
20–25	712	167 (23.5)	1.00		1.00		1.00	
25–30	517	114 (22.1)	0.91 (0.69–1.19)	0.4725	0.84 (0.62–1.139)	0.2422	0.83 (0.61–1.13)	0.2297
30–35	257	91 (35.4)	1.73 (1.26–2.36)	0.0007	1.53 (1.08–2.13)	0.0153	1.43 (1.01–2.03)	0.0462
35–40	146	48 (32.9)	1.56 (1.05–2.29)	0.0272	1.56 (1.00–2.38)	0.0489	1.34 (0.85–2.08)	0.2094
>40	0	–						

model 1: adjustment with sex and age
model 2: adjustment with sex, age, marriage status, work with income and shift work
model 3: adjustment with sex, age, marriage status, work with income, shift work, attitude to wind turbine development and visual impact.

Table 5 The difference between wind turbine noise and background noise relate to the prevalence of sleep disorder

			Odds ratio (95% confidence interval)					
	N	case (%)	model 1	p	model 2	p	model 3	p
Under 5 dB	1,642	406 (24.71)	1.00		1.00		1.00	
Over 5 dB	263	90 (34.2)	1.58 (1.20–2.09	0.0015	1.59 (1.16–2.16)	0.0042	1.48 (1.06–2.04)	0.020

model 1: adjustment with sex and age
model 2: adjustment with sex, age, marriage status, work with income and shift work
model 3: adjustment with sex, age, marriage status, work with income, shift work, attitude to wind turbine development and visual impact.

4. DISCUSSION

This epidemiologic study suggested that audible noise (frequency of 20 Hz or over) that is produced by wind power generation facilities can be a risk factor for sleep disorder when the residential environment is characterized by any of the following: 1) wind turbine sound is consciously audible, 2) residence is close to a wind turbine (within 1,500 m), 3) nighttime wind turbine noise (L_{Aeq}) is 35 dB or higher and 4) difference between nighttime wind turbine noise and background noise is 5 dB or more. The results of multiple logistic regression analysis showed that the odds ratio of sleep disorder were significantly increased in these cases. This study used a nighttime wind turbine noise (L_{Aeq}) level of 35 dB and over since this level matched the cut-off value for annoyance and sleep disorder reported by Schmidt et al (6). This same value is used in wind turbine noise standard guidelines worldwide, including in Sweden and New Zealand (7). Japan previously had no standards regarding wind turbine noise, but recently the Ministry of the Environment released an administrative notice indicating that the noise limit is 5 dB above the

background noise, but this standard is not used consistently across the country. The standard regarding the upper limit for nighttime wind turbine noise takes into consideration the characteristics of each area to make sure that no troubles arise in the living environment. The upper limit is set to 35 dB in some areas (especially those requiring greater degrees of silence) while other areas have 40 dB as the limit (8).

As for sleep disorder caused by infrasound, all wind turbine noise of 20 Hz or under that was measured in this study was below the human sensory threshold. The results are not shown, but in a sub analysis of participants who stated that wind turbine sound was inaudible (n = 1,813), the significant relationship between distance and sleep disorder disappeared, and thus the likelihood of a relationship between the two is low. Noise measurement results near wind power generation facilities across Japan showed that infrasound was not louder than other environmental noise. However, the amplitude modulation of sound and tonal components of noise generated from wind power generation facilities have a tendency to increase annoyance, and therefore further studies should evaluate their health effects. Jeffery et al.(3) also reported that even if infrasound from wind turbines does not exceed the human sensory threshold, it cannot be completely ignored since it may influence the vestibular system, and thus health effects other than sleep disorder also need to be reviewed.

The visibility of wind turbines and attitudes towards scenic views were identified as cofounding factors in previous studies, but no statistically significant effects were found in this study. In the surveyed area, attitudes toward accepting wind power generation were favorable compared to the areas in previous studies; this may have influenced the outcome, and therefore analyses are needed that take into account the characteristics of each area. Of the cofounding factors considered in this study, "attitude towards wind power generation facilities (past, present)" was most strongly associated with sleep disorder, increasing its likelihood by approximately fivefold. Sub-analysis of participants with a favorable current attitude towards wind turbines (n = 879) showed that annoyance with wind turbine noise was significantly related to distance from the wind turbine (data not shown); however, there was no significant relationship between distance and sleep disorder, and therefore it seems important to determine how to build consensus prior to introducing new wind power generation facilities. The Ministry of the Environment created a report called "Dealing with noise generated from wind power generation facilities" that points out the importance of promoting communication between stakeholders.

The limitations of this study are as follows. The collection rate of questionnaires was only 28.3%, which is low, and therefore although we confirmed that the overall population and a sample did not differ in the distribution of gender and age, the validity of the data remains to be verified. The distance from the nearest wind turbine was calculated from the location of the local public city hall to which each respondent belonged, rather than from each respondent's actual residence. This may have led to inaccuracy regarding distance information. For the estimation of the wind turbine A-weighted equivalent continuous sound level (L_{Aeq}), a distance attenuation curve <$L_{Aeq,WTN}(d) = -20.9\log_{10}d + 87.9$, where d is a distance (m)> was derived based on the measurements obtained at nine locations where wind power generation facilities were visible. These consisted of five locations in area A, with horizontal distances to the wind turbine from 337 m to 1,485 m, and four locations in area B, with distances from 944 m to 1,766 m. The validity of the estimation equation is not fully confirmed. Finally, this epidemiological research design was cross-sectional in nature, and therefore it cannot be used to determine any causal relationship between exposure to noise (cause) and health effects (result). Only the possibilities of such relationships can be identified. Longitudinal studies (cohort studies) involving wind turbine noise and health effects are rare worldwide, but these are necessary to prove causal relationships.

In Japan, based on situations involving noise complaints, the Ministry of the Environment generally defines low-frequency noise as 100 Hz or lower. Internationally, the definition of low-frequency noise differs by country and no standard exists. The International Electro-technical Commission (IEC) standard 61400 series defines infrasound as 20 Hz or lower, and low-frequency noise as 20 to 100 Hz. In Japan, the Japan Industrial Standard (JIS) uses the same definition as the IEC. Japanese environmental assessment law defines noise (frequency 20 to 100 Hz) and infrasound (frequency 20 Hz and lower), and does not use the term "low-frequency noise." Generally, in terms of wind turbine noise concerns, many residents worry about the health effects of so-called "low-frequency noise," defined as 100 Hz and below, but they also do not realize that low-frequency noise (infrasound) is inaudible. In the future, public awareness campaigns about the proper usage of

the term "low-frequency noise" are necessary not only for researchers but also for business developers and local residents. These campaigns will increase mutual understanding and the sharing of measurement results, and promote the development of new strategies regarding wind turbine noise.

REFERENCES

1. McCunney R, Mundt K, Colby D, Dobie R, Kaliski K, Blais M. Wind turbine and health: a critical review of the scientific literature. J Occup Environ Med 2014: 56: e108– e130.
2. Kubo T, Hasunuma H, Morimatsu Y, Fujino Y, Hara K, Ishitake T. Influence of low-frequency and other noise produced by wind turbines: An epidemiological literature review. Jpn J Public Health 2017; 54: 403-411.
3. Jeffery RD, Krogh CM, Horner B. Industrial wind turbines and adverse health effects. Can J Rural Med 2014: 19: 21– 26.
4. Onakpoya IJ, O'Sullivan J, Thompson MJ, Heneghan CJ. The effect of wind turbine noise on sleep and quality of life: A systematic review and meta-analysis of observational studies. Environ Int 2015; 82: 1– 9.
5. Michaud DS, Feder K, Keith SE, Voicescu SA, Marro L, Than J, Guay M, Denning A, Murray BJ, Weiss SK, Villeneuve PJ, van den Berg F, Bower T. Effects of Wind Turbine Noise on Self-Reported and Objective Measures of Sleep. Sleep 2016; 39: 97–109.
6. Schmidt JH, Klokker M. Health effects related to wind turbine noise exposure: a systematic review. PLoS One 2014; 9: e114183.
7. Tachibana H. The guidelines for wind turbine noise in foreign countries. Acoust Sci Technol 2015: 71: 198–205.
8. The Ministry of the Environment in Japan. The guideline for noise generated by wind power generations. 2017.http://www.env.go.jp/air/noise/wpg/shishin_ H2905.pdf

Infrasound.

Myocardial Contractility

Original Article

Negative Effect of High-Level Infrasound on Human Myocardial Contractility: In-Vitro Controlled Experiment

Ryan Chaban[1], Ahmed Ghazy[1], Eleni Georgiade[2], Nicole Stumpf[1], Christian-Friedrich Vahl[1]

[1]Department of Cardiothoracic and Vascular Surgery, University Hospital of Johannes Gutenberg University Mainz, Mainz, Germany, [2]Faculty of Medicine, University of Mainz, Mainz, Germany

Abstract

Background: Human exposure to infrasound is increasing due to man-made factors, such as occupational conditions, wind farms and transportation. The concern among the public regarding the safety of infrasound exposure is growing. **Aims:** To evaluate whether exposure to infrasound interferes directly with human cardiac function and contributes to pathological processes. **Setting:** The University Hospital of Mainz, Germany. **Methods:** Human myocardial tissues, obtained from patients undergoing cardiac surgery, were prepared in small muscle samples and stimulated electrically in-vitro for a period of almost two hours under physiological conditions to induce continuous pulsatile contractions and simulating a working human heart. Two samples were obtained from each donor: one was subjected to infrasound for 60 min and the other served as a control. Their contraction forces (CF) and durations (CD) were measured before and after each testing period and their relative changes ($CF_{\%}$ and $CD_{\%}$) were calculated and introduced in a multilinear regression model. The following three infrasound levels of exposure were used in this study: 100, 110 and 120 dBz. **Results:** The measured $CF_{\%}$ corresponded negatively with the infrasound level measured in dBz ($R_2 = 0.631$; $P = 0.018$). The decrease measured almost −11% at 110 dBz and −18% at 120 dBz, after correction for control. The CD on the other hand remained unchanged. **Conclusions:** Exposure to high levels of infrasound (more than 100 dBz) interferes with cardiac muscle contractile ability, as early as one hour after exposure. There are numerous additional studies which support this conclusion. These results should be taken into account when considering environmental regulations.

Keywords: Environmental legislation, heart, infrasound, laboratory researchkey messages

Key Messages

Environmental regulations should be reconsidered to set a maximum tolerated level of chronic exposure to infrasound no higher than 90 dBz, as higher level can interfere with the cardiac function

INTRODUCTION

Infrasound is a common phenomenon existing widely in nature and produced in numerous ways, such as wind and thunder. Modern society has greatly increased its generation through man-made sources, such as occupational conditions, industrial installations, vibration of mechanical equipment inside enclosed spaces (like heating and ventilation systems), wind turbines and transportation.[1-2] Opening the rear window in a car traveling at 100 km/h for example, exposes the passengers to levels of infrasound as high as 125 dBz.[1] This increase in human exposure to infrasound is historically unanticipated and has led to growing concern among the public regarding its safety.[3] This concern has been compounded by a wide spectrum of complaints, which have been reported worldwide among populations exposed to infrasound. Symptoms attributed to the effect of infrasound include, but are not limited to, headache, concentration deficit, mood change, depression, sleep disorders, pulsation and panic disorders, especially between individuals, who are exposed chronically, due to occupational conditions or by

Access this article online

Quick Response Code:

Website: www.noiseandhealth.org

DOI: 10.4103/nah.NAH_28_19

Address for correspondence: Dr. med. Ryan Chaban, Department of Cardiothoracic and Vascular Surgery, University Hospital of Johannes Gutenberg University Mainz, Langenbeckstr. 1, Mainz, Germany. E-mail: rayan.chaban@unimedizin-mainz.de

Received: 1 May 2019 **Revised:** 10 December 2019
Accepted: 3 January 2020 **Published:** 30 June 2021

How to cite this article: Chaban R, Ghazy A, Georgiade E, Stumpf N, Vahl CF. Negative effect of high-level infrasound on human myocardial contractility: In-vitro controlled experiment. Noise Health 2021;23:57-66.

I-20

their domicile residing near industrial sources.[4-5] People experiencing effects from infrasound often describe it as a deep humming vibration in their body, or in external objects around them.[4] Some individuals even report being able to hear it, which sheds light on the common misconception regarding the audibility of infrasound, as many individuals, including professionals, equate infrasound (acoustical frequencies less than 20 Hz) to be inaudible sound. In fact, it has been shown as early as the 1930s that infrasound can still be perceived when the pressure level is high enough.[4,6-8]

Several experimental and environmental studies have suggested the association between infrasound and negative effects on public health.[3,9-11] Many animal tests found infrasound to negatively affect the heart,[12] liver,[13] nervous system[14] and the lungs.[15] However, it is still not known to what extent such negative effects happen in an everyday-life environment. Also, the exact mechanism by which infrasound affects human health, including which organs are especially at risk, is still common topic of discussion.

Cardiac function is the result of a very finely tuned mechanical system, requiring continuous cyclic interaction between actin and myosin to produce a powerful contraction, enabling the pumping of blood throughout the body. It is still unclear what effects the high energy levels of infrasound (acoustic vibration below 20 Hz) have on the heart.

This research attempts to answer this question by investigating the effect of exposure to high levels of infrasound on cardiac contractility. The first objective in this study is to evaluate whether or not infrasound affects heart muscle tissue. The second objective is to attempt to quantify this effect, if it exists, and to extrapolate its relevance in the modern-day environment. To accomplish this, we subjected human cardiac tissue obtained from the right atrium to infrasound directly in an in-vitro model, isolating the tissue from all other factors interfering with its function. We used three different energy levels of exposure (100, 110 and 120 dBz). These energy levels fall relatively in a gray zone, since levels above 120 dBz are well known to be dangerous to humans.[11]

METHODS

Ethics approval

This study was conducted after obtaining clearance from the Ethics Board of Rhineland-Palatinate, Germany. We obtained individual written consent from patients for the use of disposed tissue arising from the surgical procedure(s), with the assurance of anonymity. No personal information was collected in this study.

Experimental tissue and preparation

Tips of the right atrial appendages that were routinely removed and discarded from patients undergoing cardiac surgery during the establishment of a cardiopulmonary bypass were collected. Tissues were excluded in the presence of the following condition: age >90 or <18 years; severe cardiomyopathy, defined as an ejection fraction (EF) $\leq$ 30%; inflammatory or infective cardiac disease (e.g., endocarditis); congenital malformations; surgery for pathologies involving the right atrium, for example, tricuspid regurgitation; digitalis therapy; and the history of atrial fibrillation or flutter. Standard cardiovascular anesthesia was applied using total intravenous protocols with propofol and remifentanil. Noradrenaline, physiological solutions for volume substitution and atropine were frequently used as required.

The samples from 18 patients were transported immediately after the surgical excision to our laboratory in a cold (4°C) modified Bretschneider cardioplegic solution (MBSC, prepared by *the pharmacy of the University Medical Center of the Johannes Gutenberg University*, Mainz, Germany), which contained 15 mM NaCl, 10 mM KCl, 4 mM MgCl(H2O)6, 18 mM Histidine.HCl.H2O, 180 mM Histidine, 2 mM Tryptophan, 30 mM Mannitol and 0.015 mM CaCl2.(H2O)2 and has a pH-value of 7.2 (25°C). They were manually prepared under the microscope to yield muscle specimens measuring $3 \times 0.5 \times 0.5 mm^3$ [Figure 1]. Following, these specimens were stored in dark cold (4°C) oxygenated MBS solution for 1–24h, before being used in experiments.

Infrasound application

A 30 cm Woofer was connected to a power amplifier, to a computer, and fixed at the top of a special made closed chamber, where the muscle investigation system was inserted. A feedback loop, consisting of measurement microphone (calibrated Superlux ECM999) and microphone amplifier was connected back to the computer. A special software (TrueRTA Audio Spectrum Analyzer), was used to generate a pure sinusoidal 16Hz signal and to analyze the measurement, verifying the exposure level. Figure 2 illustrates this design.

Three sets of trials were conducted using three different infrasound levels: 100, 110 and 120 dBz. Infrasound measurement was conducted using no weighting (known as Z-weighting or linear weighting).

Trial preparation

At the beginning of each experiment, every specimen was washed with the Krebs–Henseleit (KH) buffer – which contained: 118 mM NaCl, 25 mM NaHCO3, 4.6 mM KCl, 1.2 mM KH2PO4, 1.2 mM MgSO4, 1.3 mM CaCl2 and 11 mM glucose – and warmed for approximately 10 min. It was then mounted horizontally between two tweezers of a muscle investigation system (modified 'Standard System for Muscle Investigation,' SH Heidelberg, Heidelberg, Germany) and exposed to a continuous flow of warm (35°C) KH buffer, steamed with a mix of 95% oxygen and 5% carbon dioxide at a rate of 0.5 mL/min. After a precise

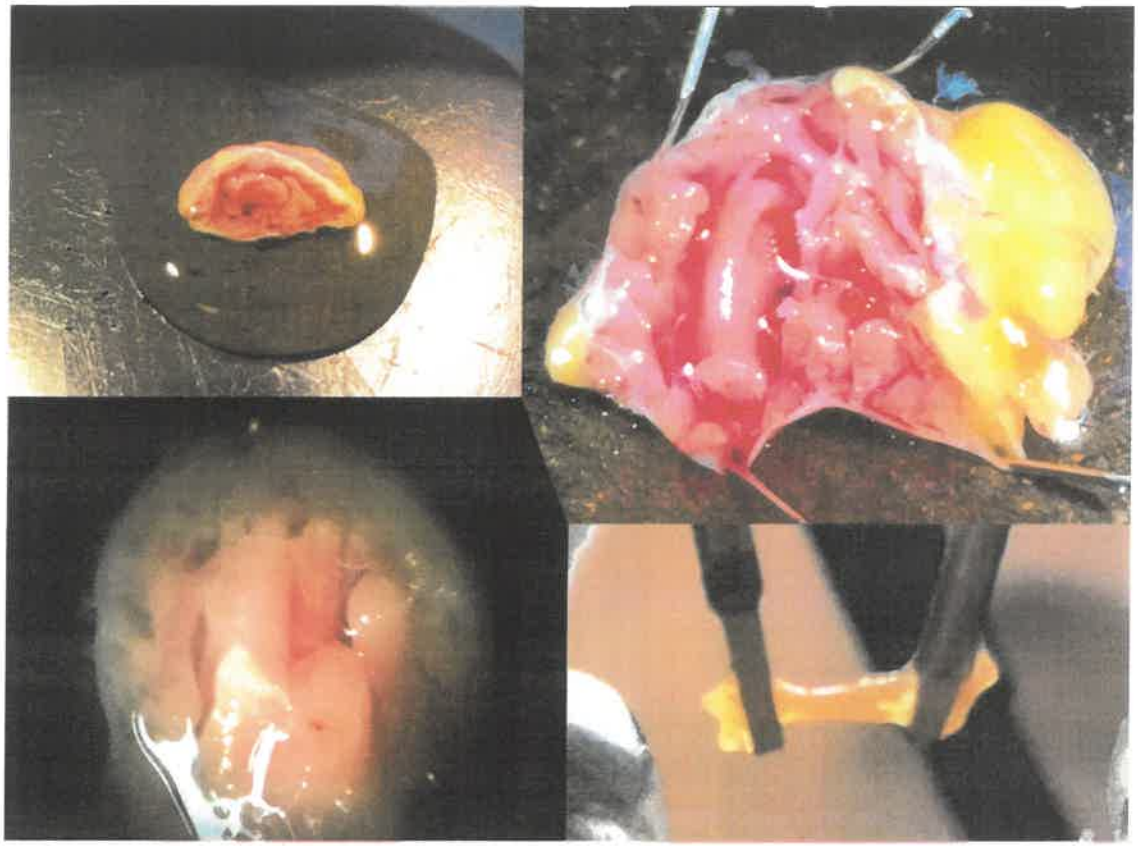


Figure 1: Preparing the atrial muscle specimens. The right atrium appendage (top left) is fixed with needles (above right) to prepare the Trabeculae carneae manually and carefully under the microscope (bottom left) to get strips measuring 3 × 0.5 × 0.5 mm^3, which are fixed between two tweezers of the muscle investigation system (bottom right).

baseline length measurement, it was stretched to 110% of its slack length. Next, electrical stimulation (field stimulation) was applied at a frequency of 75 bpm. The voltage was gradually increased from 1 V to a maximum of 10 V, until the maximal contraction force (CF) of the specimen was reached. Following, it was left to stabilize for 30 min to reach a steady state before starting the experiment.

Experiment design

Two samples, obtained from the same patient, were stimulated simultaneously in each experiment with only one of them exposed to infrasound and the other serving as a control. Two identical muscle investigation systems were used for this purpose. Each experiment was conducted using samples from a different donor. The exposure to infrasound lasted 60 min. The samples were allowed to beat for another 30 min before ending the experiments. Figure 3 explains the design used for this study.

Data analysis and statistical assessment

We relied on the "PicoScope 2204A Pico Technology, Cambridgeshire, UK", using the "PicoLog Software" for data acquisition and recorded the complete trials as plain "txt" files. The data were then processed with Excel 2016 (Microsoft Corp., Redmond, WA, USA). A self-developed Macro (available as supplement) was used to calculate the two variables measured in this study: the contraction forces (CF) and duration (CD). Figure 4 provides an optical explanation for the calculation process. The measurement was repeated twice: directly before applying the Infrasound (CF_1 and CD_1) and after (CF_2 and CD_2). Each measurement lasted 10 min and the average values were recorded. Following, the relative changes ($CF_{\%}$ and $CD_{\%}$) were calculated according the following equation:

$$CF\% = 100 \times CF2 / CF1$$

Using the relative changes in the statistical evaluation, instead of the absolute values was necessary to adjust for the diversity of the muscle specimens and their initial forces, which resulted from the manual preparation. This approach was found justifiable as this research was only interested in studying the changes induced by the infrasound and not the samples themselves. As those ratios tend usually to contradict the gaussian distribution and follow an exponential pattern, we performed a logarithmic transformation, before finally analyzing their logarithms using a *multiple linear*

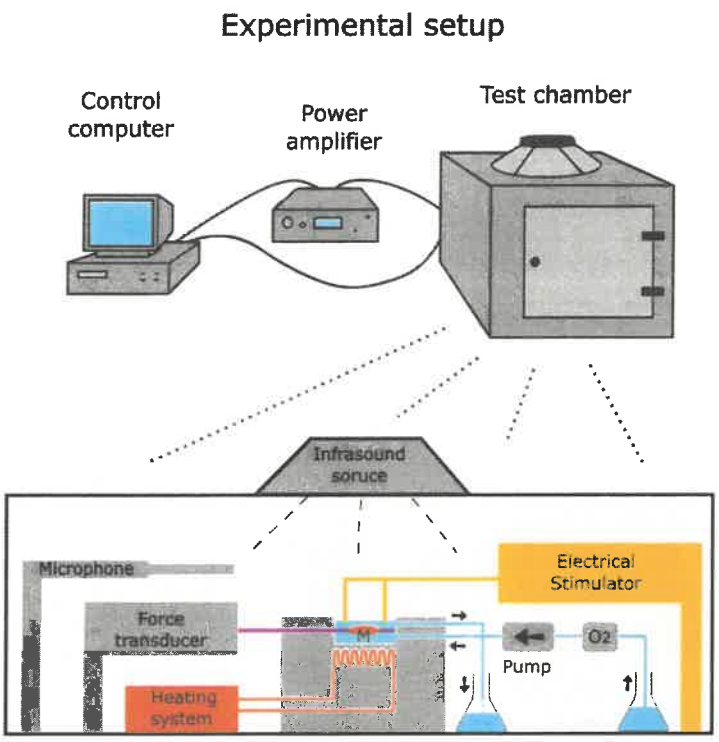


Figure 2: A computer is connected to a power amplifier to an infrasound woofer, which is mounted at the top of the test chamber, which is specially constructed to allow levels of infrasound up to 130 dBz and houses the muscle investigation system inside of it. A measurement microphone is included to ensure a steady level of infrasound throughout the experiments. The cardiac sample (M) is brought inside, where it is electrically stimulated to perform pulsatile contraction at a frequency of 75 bpm, simulating a working human heart. The contraction force and duration are measured then.

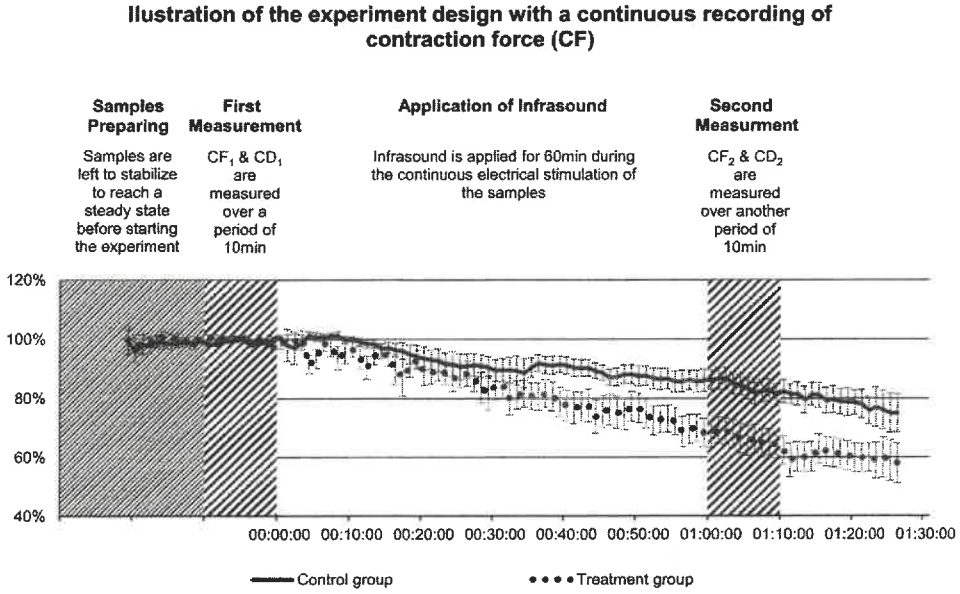


Figure 3: Experiment design: First the samples are stimulated for a period of 30min until they reach a steady state. Then the CF and CD are measured over a period of 10 min (CF_1 and CD_1). Infrasound is applied for a period of 60 min during the continuous electrical stimulation to only one of the two samples. The second one serves as a control. At the end, the measurement is repeated over a further period of 10 min (CF_2 and CD_2). Lastly, the relative changes ($CF_{\%}$ and $CD_{\%}$, the ratio between the values after the treatment and before) are calculated for both the test and control samples.

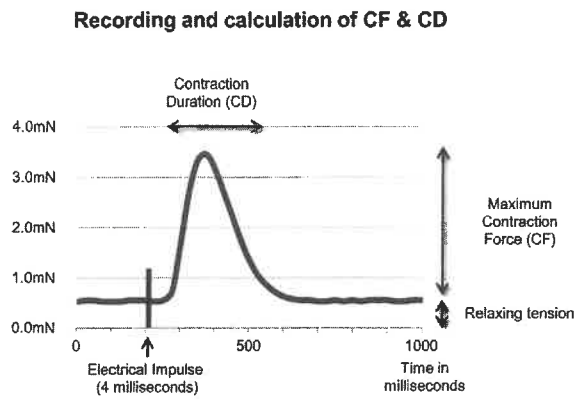


Figure 4: The maximal isometric contraction force (CF) and duration (CD) were calculated directly from the continuous registration of force.

Table 1: Summary of the medical profiles and medications of the patients ($n = 18$)

Medical situations, treatments and medications	Frequency	Ratio (%)
Aortic valve replacement	8	44
Mitral valve repair/replacement	4	22
Coronary artery bypass graft	11	61
Coronary artery disease	12	67
Atrial fibrillation	3	17
Severely reduced ejection fraction	0	0
Moderately and slightly reduced EF	2	11
Diabetes mellitus	9	50
Mitral valve insufficiency	6	33
Arterial hypertension	17	94
Renal insufficiency	1	6
Aspirin	9	50
Beta blockers	11	61
Statins	9	50
Diuretics	7	39
Metformin	3	17
Thyroxine replacement therapy	2	11
Antihypertensive medications	14	78

regression model. We considered *CF%_test* (the relative change in the corresponding test sample) as a dependent variable and both the corresponding *CF%_cont* (the relative change in the corresponding control sample) and *infrasound_level* as the explanatories. Values were finally reported as ratios for clarity.

Statistical Analysis was done using XLSTAT Statistics. Descriptive variables were described by frequencies and quantitative variables by mean. We verified the normality of the measured values using the *Anderson-Darling Test*. The sample size needed in this work was determined after conducting primary trials, using the same model. By setting the statistical power to 0.8, six trials were needed for each group. This decision was also augmented by our experience with this model in previous researches.[16] Only one-tailed *P*-value was computed as we expected a negative effect of Infrasound based on our literature research. An *a*-value of 0.05 was chosen for significance.

RESULTS

Six trials for each of the three groups were conducted. The average of age of the 18 donors was 67.8 ± 8 years (mean $\pm$ SD), eight of which were female and ten were male. Table 1 illustrates their patient profile. No significant differences in patient characters were seen between the three groups.

The measured *CF%_test* (treated with infrasound) were found to correlate positively with the *CF%_cont* ($p = 0.0003$) and negatively with the *Infrasound_level* ($p = 0.018$). The *CF%_test* measured almost −11% less than the *CF%_cont* at 110dBz and −18% at 120dBz (after correction for *CF%_cont*). The following predicting model was calculated ($R2 = 0.631$; $P = 0.0006$):

$$Log(CF\%\_test) = 0.892 - 0.0048 \times Infrasound\_level + 0.778 \times Log(CF\%\_cont)$$

Exposure to infrasound did not alter the contraction duration (CD) in any group ($P = 0.765$). Table 2 and Figure 5 illustrate the results.

Table 2: The measured CFs of all trials in millinewton with their relative changes ($CF_{\%}$)

	Contraction Force (CF) in millinewton																	
Trial	Group A: 100 dBz						Group B: 110 dBz						Group C: 120 dBz					
	Control			Test			Control			Test			Control			Test		
Nr.	Bef	Aft		Bef	Aft		Bef	Aft		Bef	Aft		Bef	Aft		Bef	Aft	
1	1.7	1.6	92%	2.4	2.4	99%	2.8	2.4	84%	1.4	1.2	82%	1.6	1.3	80%	0.8	0.5	65%
2	2.0	1.6	79%	1.3	0.9	64%	1.4	1.2	85%	2.2	1.3	61%	2.0	1.7	88%	2.8	2.4	86%
3	1.6	1.2	75%	1.4	1.1	78%	1.4	1.3	94%	3.6	3.1	85%	1.6	1.3	80%	1.0	0.9	82%
4	1.5	1.4	94%	2.0	1.7	86%	0.8	0.3	40%	0.3	0.1	41%	2.1	1.8	87%	1.3	0.8	64%
5	2.9	2.7	94%	3.3	3.2	99%	2.3	2.5	107%	1.3	1.0	72%	1.0	1.0	99%	0.6	0.3	61%
6	0.9	0.4	47%	0.4	0.2	49%	2.1	1.5	69%	2.2	1.5	69%	2.8	2.0	71%	1.7	0.8	43%

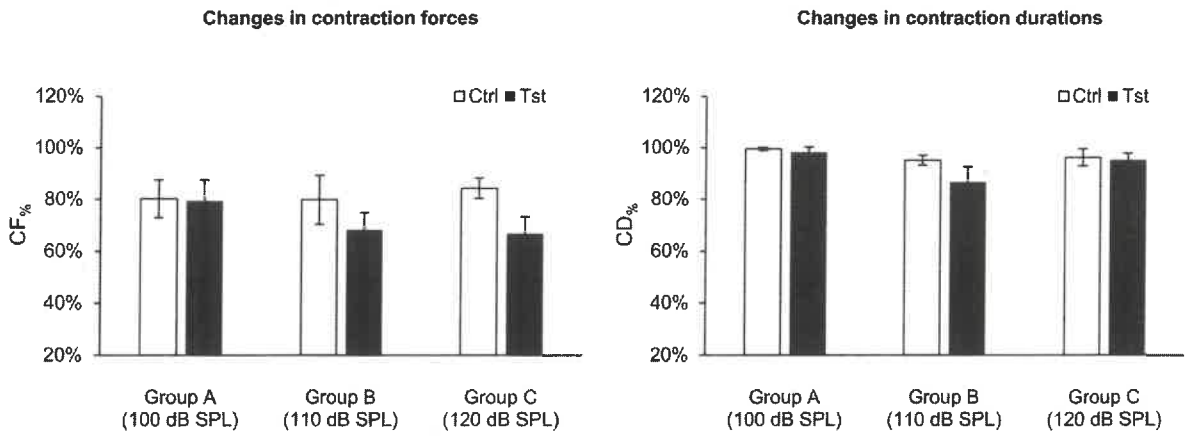


Figure 5: The measured contraction forces (CF) after exposure to infrasound were negatively corresponded to Infrasound_level measured in dBz ($P = 0.018$). The $CF_{\%}$_test decreased almost 11% against the $CF_{\%}$_cont at 110 dBz and 18% at 120 dBz. Exposure to infrasound did not alter the contraction duration (CD) in any group ($P = 0.765$).

DISCUSSION

This study shows a strong negative effect of exposure to high level of infrasound (above 100dBz) on the contractility of cardiac tissues in-vitro. This finding is unique, as it is the first evidence to demonstrate such a direct effect of infrasound on the cardiac function in humans. The measured effect of almost 9% decrease in contraction force for every 10 dBz above 100 dBz is relevant, especially when considering that this effect was observed after only one hour of exposure.

Interpreting the significance of this finding in an everyday environment requires some clarification regarding the physical character of infrasound and its effects on the whole body protecting the human heart. Infrasound is the extension of the audio spectrum, when the frequency falls below 20 Hz. As a result, it shares much with the audible spectrum, but with some unique characteristics. The very long wavelength (considering the acoustic velocity of 343m/s at 20° dry air see-level, there is a wavelength of more than 17.5 m) compared to the audible sound, enables infrasound, by means of reflection; refraction and diffraction, to pass through and around different obstacles, such as buildings and terrains. The long wavelength also allows infrasound to maintain energy, remaining relatively stable after traveling long distances. For the same reason, common noise barriers are usually ineffective against it. It is also the same reason why it is usually not a simple procedure to locate infrasound sources, even when many individuals, who describe a feeling of a drum in their entire body, easily perceive it.

It is also common for infrasound to generate high energetic standing waves in enclosed spaces, when the space dimensions are multiples of the half wavelength of some externally or internally presented infrasound signal, increasing the infrasound level further by condensing its energy by means of resonance.[17] This kind of resonance, also known as *Helmholtz resonance*, sometimes leads to infrasound increasing inside of residential rooms with open windows, or through ventilation ducts and affecting people by reaching levels up to 25dBz higher than the measured level outside.[18] It also partially explains why some people may complain about infrasound without even being in the direct vicinity of its sources, with other individuals not perceiving effects at all, and why the complaints are often about indoor disturbance instead of outdoor.[4] For example, while some outdoor measurements may read a level of 80 dB, at the same time in a nearby living room 100 db can be present.

The human body itself does not shield against infrasound. In contrast, it may emphasize it by mean of resonance, as it has been shown that the upper human torso tends to resonate between 5 and 250 Hz.[19-20]

An area needing clarification is the ambiguity inherent in the measuring methods presently used regarding audible noise and infrasound. While most legislation and regulations specify the maximum tolerated noise level using the A-weighting system, it is important to define the nature of this system. The A-weighted acoustic measuring method is specifically designed to diminish the inaudible part of the acoustic spectrum. As a result, an exposure to a high-level 100 dBz infrasound signal with a frequency of 16 Hz would measure merely $45dB_{(A)}$, deeming it acceptable according to many of the present-day noise regulations. Figure 6 clarifies this weighting system.

Epidemiological studies regarding infrasound are usually difficult to conduct and are often inefficient. People under infrasound exposure may not notice it as infrasound, since it is not usually audible or perceptible, which may lead them not to participate in such studies. The ability to sense or hear infrasound is extremely subjective, exaggerating its unpleasant presence by some individuals.[11] In contrast to epidemiological studies, laboratory research has been conducted extensively regarding infrasound, especially during the 1970s and 1980s in the Soviet Union with many interesting results, which need to be discussed here.

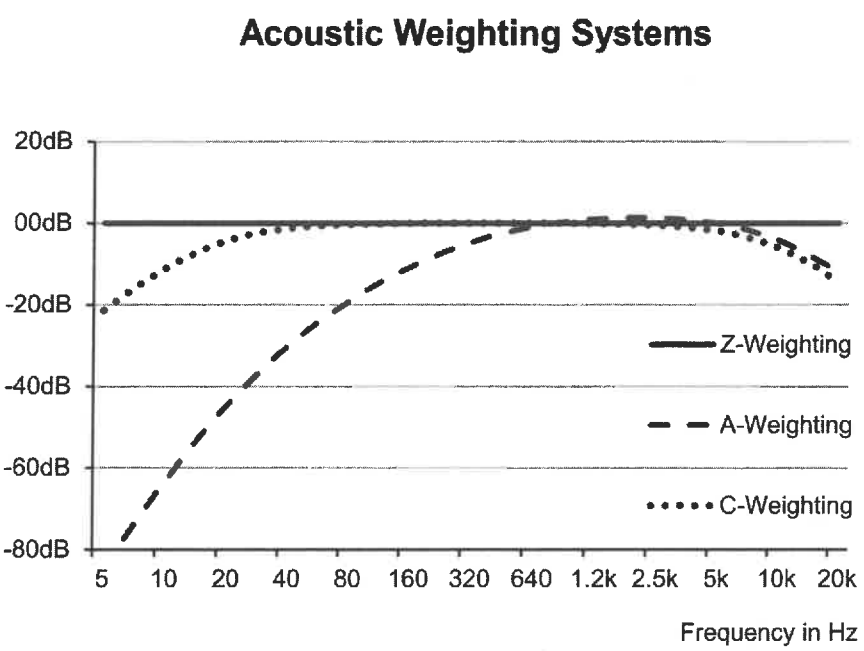


Figure 6: Acoustic measurement according to the DIN EN 61672-1:2014-07 standard. [21] Noticed how applying the A-weighting attenuates the signal in the low-frequency region up to more than 80 dB, as compared to the Z-weighting (no filter). C-weighting is another commonly used filter, which falls in between.

The workgroup of Karpova *et al.*[22] concluded that levels of 110 to 132dB at frequencies of 1 to 12Hz are possible near sources such as diesel engines; turbines; piston pumps; compressors; fans and other large air blowing machines. They went further to test the effect of these levels on healthy young men at age from 19 to 29 years and found them to cause mental stress; vegetative reactions and unpleasant auditory sensation, already after the first minute of exposure. Further symptoms were a feeling of general fatigue, lethargy, pressure in the ears, dizziness, distraction, drowsiness and feeling of depression during the next 15 min of exposure. By examining the effect on the heart, the same group noticed changes in cardiac rhythm and arrhythmia. Using an old technique known as the seismic cardiograph, they also noticed a reduction in the force of contraction of the heart muscle, with the most pronounced changes induced by frequency of 10 Hz. Another soviet workgroup, Gordeladze *et al.*[12], examined the effect of infrasound at a frequency of 8 Hz and intensity of 120dB on white rats and guinea pigs.[12] As soon as after 3 hours of exposure, they noticed pallor and swelling of the left and right ventricular walls with small-point hemorrhages in the pericardium. Microscopically, mitochondrial swelling, with destruction of outer membranes and endothelial swelling were noticed. After a day of exposure, the activity of redox enzymes had fallen; the sarcoplasm of cardiomyocytes was edematous; the sarcolemma was damaged in a number of areas and the mitochondrial swelling continued to exist. After 5 days cardiomyocytes began to show signs of granular dystrophy; the activity of redox enzymes was reduced; the myofibrils were fragmented in the areas of the discs; the mitochondria were swollen with cristae being finely fragmented; the erythrocytes accumulated in the lumens of the dilated capillaries and the swollen endothelial cells included destroyed mitochondria. Changes in the nuclei were noticed after 25 days with rugged contours; chromatin located in the form of clumps of various sizes and enlarged pores. Full restoration of damaged cardiac cells was noticed after the termination of infrasound exposure though. Similar results were noticed by the same team in another work studying the effect of infrasound on the liver cells.[23] Using the same experimental setup, they noticed resembling changes in both the cytoplasm und the nucleus, with redistribution of chromatin and concentration in the form of dense layer under the nucleus membrane and increased RNA content. Myelin like bodies and lipid granules appeared in a number of hepatocytes on the 25th and 40th day. There was also a decrease in the number of ribosomes. The Mitochondria were swollen and contained shortened and fragmented cristae. Obviously, the infrasound damaged not only intracellular structure and mitochondria, but also the nuclear apparatus.

There is plenty of evidence regarding the damaging effect of infrasound upon the heart. After exposing Sprague-Dawley rats to 5 Hz infrasound at 130 dBz for 3 hours daily, Pei *et al.*[9] found changes in cardiac ultrastructure, hemodynamics indices, intracellular Ca_2^+ concentrations and sarcoplasmic reticulum Ca_2^+. Further, the heart rates increased significantly in comparison to a control group in

the first day of exposure. Maximum dropping rates of left ventricular pressure (corresponding to the diastolic function) were significantly decreased. There were also several swollen mitochondria and platelet aggregation in the intercellular space of the exposure group, the same finding which has been previously reported by Gordeladze *et al.*[12] and Alekseev *et al.*[24] in the 1980s. Prolonged exposure altered the L-type Ca_2^+ currents as well.[25] Pei *et al.*[26] also investigated the apoptotic effect of infrasound on neonatal rat cardiomyocytes by exposing them to 5Hz at 130dB for several days and found that infrasound induces apoptosis in a time-dependent manner. The expression of proapoptotic proteins such as Bax, caspase-3, caspase-8, caspase-9 and FAS was significantly up-regulated, with concomitant down-regulated expression of antiapoptotic proteins. Another underlying mechanism for the damage induced by infrasound is the oxidative stress, which was also investigated by the same team, who found the expression of CAT, GPx, SOD1 and SOD2 and their activities in rat cardiomyocytes in infrasound exposure groups were significantly decreased compared to controls, along with significantly higher levels of O_2 and H_2O_2.[27] Further, Lousinha *et al.*[28] showed that exposure to 90 to 145dB infrasound induces coronary perivascular fibrosis in rats. It is worth mentioning here that Pei *et al.* used very high level of Infrasound (130 dB) in their experiments to induce these effects. Besides, they exposed cardiomyocytes in their experiment directly to infrasound, without a protection of surrounding tissues. Whether cardiomyocytes are ever exposed to such levels of infrasound in in-vivo and in real world environment remains questionable. On the other hand, examining the effect of moderate, chronic, real-world exposure to infrasound over an extended time period is much more challenging and is not feasible in laboratory conditions.

Infrasound also can exert a negative effect on the cardiovascular system in an indirect way. As we previously discussed, many people can hear it or perceive it through their body and for them it is another form of noise, which is associated with mental stress. It is currently well known that noise can cause oxidative stress; vascular dysfunction and inflammation, resulting in adverse cardiovascular effects and ultimately leading to cardiac remodeling and fibrosis.[29-32]

Wind turbines are being built faster than ever, invading new geographic locations every day, further increasing potential exposure to infrasound. They are usually well accepted with positive attitude toward them, being a source of green energy and helping in reduction of atmospheric carbon dioxide with no further known gaseous emissions.[33] Nevertheless, people on a local level and residents in their immediate vicinity sometimes oppose them. These individuals are frequently reporting annoyance, headache, concentration difficulty, irritation and sleep disorders.[11,34] Similar complaints, like drowsiness, numbness, ear pressure, nausea and breath depression, are well described under laboratory conditions and after a short exposition to high level of infrasound.[10,35-36] Thus, it seems reasonable to attribute some complaints about wind turbines to the infrasound radiated by them. Disagreement exists though regarding the exact level of infrasound emission by wind turbines and its geographical extent. The tendency toward building larger wind turbines to achieve more electrical power is ongoing, with a multitude of projects being currently under consideration or construction worldwide. Whether or not wind turbines are, or will be, able to produce harmfully high levels of infrasound, levels that are associated with pathological changes similar to those previously discussed, remains out of the scope of this paper. However, with all the physical effects discussed above and as medical researchers, it is strongly recommended to conduct adequate physical examinations and measurements under real world conditions to assure that infrasound levels generated by wind turbine farms do not approach pathological levels. The researchers of this article recommend setting the level of generated infrasound as low as 80 dBz (20 dBz below the critical value of 100 dBz) as the maximally tolerated limit for chronic exposure; this recommendation is similar to the 85 $dB_{(G)}$ level recommended by the Danish Environmental Protection Agency in 1997.[37]

Finally, the following points need to be considered. The myocardial samples used in this work were obtained from a typical cardiac-surgery population, consisting of elderly individuals with a variety of cardiac pathologies. There are known differences between atrial und ventricular myocardium, such as approximately 15% smaller atrial cell volume yielding higher surface-to-volume ratio; smaller amplitude of systolic Ca_2^+ transients; accelerated rates of decline of systolic Ca_2^+; more sarcoplasmic reticulum (SR) mediated Ca_2^+ uptake and higher SR Ca_2^+ content.[38] Additionally, a higher density of mitochondria is found usually in ventricles.[39] However, these differences are merely quantitative and do not constitute new mechanisms or pathways.[40-41] Hence, it is acceptable to use the atrial tissues in our investigation, especially when the target is screening for possible effects.

CONCLUSION

Exposure to high level of infrasound (more than 100 dBz) negatively interferes with cardiac function, even as soon as one hour after exposure. Numerous independent laboratory research from around the globe has been performed, resulting in similar findings supporting this conclusion. The effect of infrasound goes obviously beyond the direct mechanical effect in increasing the cross-bridge breakage and involves a wide range of processes, such as calcium metabolism und mitochondrial integrity. These results should be considered when looking at environmental regulations. It is the recommendation of this research group to set the level of infrasound no higher than 80dBz as the maximally tolerated limit for chronic exposure.

DISCLAIMER

Ethics approval

All procedures performed in this study involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. This study was performed with the permission of the Ethics Board of Rhineland-Palatinate, Germany.

This article does not contain any studies with animals performed by any of the authors.

Informed consent

Informed consent was obtained from all individual participants included in the study.

Consent to publish

Not applicable.

Availability of data and material

The datasets used during this study are available as supplements and from the corresponding author upon reasonable request.

Conflicts of interest

There are no conflicts of interest.

Financial support and sponsorship

This work was completely and exclusively funded by the department of Cardiothoracic and Vascular Surgery, University Hospital of Johannes Gutenberg University Mainz, Germany. The University provided all the needed instruments and equipment, as well as the human resources.

The corresponding author confirms that all authors have read and approved this manuscript.

The data used in this work are part of the medical thesis work of the co-author Ms E. Georgiade.

References

1. Ziaran S. The assessment and evaluation of low-frequency noise near the region of infrasound. Noise Health 2014;16:10-7.
2. Piorr D, Wietlake KH. Assessment of low frequency noise in the vicinity of industrial noise sources. J Low Freq Noise Vib 1990;9:116.
3. Baliatsas C, van Kamp I, van Poll R, Yzermans J. Health effects from low-frequency noise and infrasound in the general population: Is it time to listen? A systematic review of observational studies. Sci Total Environ 2016;557:163-9.
4. Møller H, Lydolf M. A questionnaire survey of complaints of infrasound and low-frequency noise. J Low Freq Noise Vib 2002;21:53-63.
5. Leventhall G. Low frequency noise and annoyance. Noise Health 2004;6:59.
6. Brecher GA. Die untere Hör- und Tongrenze. Pflügeres Arch Physiol 1934;280:380.
7. Von Békésy G. Über die Hörschwelle und Fuhlgrenze langsame sinusförmiger Luftdruckschwankungen. Ann. Physik 1936;26: 554-66.
8. Leventhall G. Review low frequency noise. What we know, what we do not know, and what we would like to know. J Low Freq Noise Vib 2009;28:79-104.
9. Pei Z, Sang H, Li R, Xiao P, He J, Zhuang Z, Zhu M, Chen J, Ma H. Infrasound-induced hemodynamics, ultrastructure, and molecular changes in the rat myocardium. Environ Toxicol 2007;2:169-75.
10. Wysocki K, Schultz K, Wieg P. Experimentelle Untersuchungen zum Einfluss von Infraschalldruck auf den Menschen. Z ges Hyg 1980;26:436:440.
11. Leventhall G. What is infrasound? Prog Biophys Mol Biol 2007;93:130-7.
12. Gordeladze AS, Glinchikov VV, Usenko VR. Experimental myocardial ischemia caused by infrasound. Gig Tr Prof Zabol 1986;6:30-33.
13. Nekhoroshev AS, Glinchikov VV. Reaction of hepatocytes to infrasound exposure. Gigiena i Sanitariia 1991;2:45-7.
14. Liu J, Lin T, Yan X, Jiang W, Shi M, Ye R, Rao Z, Zhao G. Effects of infrasound on cell proliferation in the dentate gyrus of adult rats. Neuroreport 2010;21:585-9.
15. Svigovyi VI, Glinchikov VV. Effect of infrasound on pulmonary structure. Gig Tr Prof Zabol 1987 34-7.
16. Chaban R, Kornberger A, Branski N, *et al.* In-vitro examination of the positive inotropic effect of caffeine and taurine, the two most frequent active ingredients of energy drinks. BMC Cardiovasc Disord 2017; Published online: 10 August 2017. doi: 10.1186/s12872-017-0625-z
17. Ziaran S. Potential health effects of standing waves generated by low frequency noise. Noise Health 2013;15:237-45.
18. Vinokur R. Infrasonic sound pressure in dwellings at the Helmholtz resonance actuated by environmental noise and vibration. Applied Acoustics 2004;65:143-51.
19. Smith SD. Characterizing the effects of airborne vibration on human body vibration response. Aviat Space Environ Med 2002;73:36-45.
20. Randall JM, Matthews RT, Stiles MA. Resonant frequencies of standing humans. Ergonomics 1997;40:879-86.
21. Electroacoustics – Sound level meters – Part 1: Specifications (IEC 61672-1:2013); German version EN 61672-1:2013. 2014. Available at https://dx.doi.org/10.31030/2154580.
22. Karpova NI, Alekseev SV, Erokhin VN, Kadyskina EN, Reutov OV. Early body reaction to low-frequency acoustic oscillations. Gig Tr Prof Zabol 1979;10:16-9.
23. Alekseev SV, Glinchikov VV, Usenko VR. Reaction of the liver cells to the impact infrasound. Gig Tr Prof Zabol 1986;9:57-9.
24. Alekseev SV, Glinchikov VV, Usenko VR. Myocardial ischemia in rats exposed to infrasound. Gig Tr Prof Zabol 1983;8:34-8.
25. Pei Z, Zhuang Z, Xiao P, Chen J, Sang H, Ren J, Wu Z, Yan G. Influence of infrasound exposure on the whole L-type calcium currents in rat ventricular myocytes. Cardiovasc Toxico 2009;9:70-7.
26. Pei Z, Chen BY, Tie R, Zhang HF, Zhao G, Qu P, Zhu XX, Zhu MZ, Yu J. Infrasound exposure induces apoptosis of rat cardiac myocytes by regulating the expression of apoptosis-related proteins. Cardiovasc Toxicol 2011;4:341-6.
27. Pei Z, Meng R, Zhuang Z, Zhao Y, Liu F, Zhu MZ, Li R. Cardiac peroxisome proliferator-activated receptor-γ expression is modulated by oxidative stress in acutely infrasound-exposed cardiomyocytes. Cardiovasc Toxicol 2013;4:307-15.
28. Lousinha A, R Oliveira MJ, Borrecho G, Brito J, Oliveira P, Oliveira de Carvalho A, *et al.* Infrasound induces coronary perivascular fibrosis in rats. Cardiovasc Pathol 2018;37:39-44.
29. Babisch W. Cardiovascular effects of noise. Noise Health 2011;13:201-4.
30. Münzel T, Sørensen M, Gori T, Schmidt FP, Rao X, Brook J. Environmental stressors and cardio-metabolic disease: Part I-epidemiologic evidence supporting a role for noise and air pollution and effects of mitigation strategies. Eur Heart J 2017:38:550-6.

31. Münzel T, Sørensen M, Gori T, Schmidt FP, Rao X, Brook FR. Environmental stressors and cardio-metabolic disease: part II-mechanistic insights. Eur Heart J 2017;38:557-64.
32. Cai Y, Hansell AL, Blangiardo M, Burton PR, *et al.* Long-term exposure to road traffic noise, ambient air pollution, and cardiovascular risk factors in the HUNT and lifelines cohorts. Eur Heart J 2017;38:2290-6.
33. World Health Organization. Energy, sustainable development and health. Fourth Ministerial Conference on Enviromental and Health. Budapest (2004).
34. Van Kamp I, Van den Berg F. Health effects related to wind turbine sound, including low-frequency sound and infrasound. Acoustics Australia 2018;46:31-57.
35. Karpova NI, *et al.* Early response of the organism to low-frequency acoustical oscillations. Noise and Vibration Bulletin 1970;11:100-3.
36. Evans MJ, Tempest W. Some effects of infrasonic noise in transportation. Journal of Sound and Vibration 1972;22:19-24.
37. Miljøstyrelsen, "Lavfrekvent støj, infralyd og vibrationer i eksternt miljø (in Danish, trans: "Low-frequency noise, infrasound and vibrations in the environment, Orientation no. 9 from the Danish Environmental Protection Agency")", 1997, Orientering fra Miljøstyrelsen nr. 9, 1–50, Miljøstyrelsen, Denmark.
38. Walden AP, Dibb KM, Trafford AW. Differences in intracellular calcium homeostasis between atrial and ventricular myocytes. J Mol Cell Cardiol 2009;49:463-73.
39. Tanaami T, Ishida H, Seguchi H, *et al.* Difference in propagation of Ca_2^+ release in atrial and ventricular myocytes. Jpn J Physiol 2005;55:81-91.
40. Vannier C, Veksler V, Mekhfi H, *et al.* Functional tissue and developmental specificities of myofibrils and mitochondria in cardiac muscle. Can J Physiol Pharmacol 1996;74:23-31.
41. Palmer S, Kentish JC. Developmental differences and regional similarities in the responses of rat cardiac skinned muscles to acidosis, inorganic phosphate and caffeine. J Mol Cell Cardiol 1996;28:797-805.

Bulletin of Science, Technology & Society
31(5) 414–426

DOI: 10.1177/0270467611417852
http://bsts.sagepub.com
SAGE

Wind Turbines Make Waves: Why Some Residents Near Wind Turbines Become Ill

Infrasound & Noise disorders

Magda Havas[1] and David Colling[2]

Abstract

People who live near wind turbines complain of symptoms that include some combination of the following: difficulty sleeping, fatigue, depression, irritability, aggressiveness, cognitive dysfunction, chest pain/pressure, headaches, joint pain, skin irritations, nausea, dizziness, tinnitus, and stress. These symptoms have been attributed to the pressure (sound) waves that wind turbines generate in the form of noise and infrasound. However, wind turbines also generate electromagnetic waves in the form of poor power quality (dirty electricity) and ground current, and these can adversely affect those who are electrically hypersensitive. Indeed, the symptoms mentioned above are consistent with electrohypersensitivity. Sensitivity to both sound and electromagnetic waves differs among individuals and may explain why not everyone in the same home experiences similar effects. Ways to mitigate the adverse health effects of wind turbines are presented.

Keywords

wind turbine, dirty electricity, power quality, ground current, contact current, electrohypersensitivity, noise, infrasound, vibroacoustic disease, wind turbine syndrome

Introduction

With growing concern about climate change, the carbon budget, depletion of fossil fuels, air pollution from dirty coal, radiation from nuclear power plants, and the need for a secure energy supply, more attention and funding are being diverted to renewable energy. Among the various types of renewable energy, wind has received a lot of attention due, in part, to opposition from communities earmarked for wind turbines and from communities that have experienced wind turbines firsthand.

Some people who live near wind turbines report difficulty sleeping and various symptoms of ill health and attribute these problems to noise and shadow flicker—two elements they can perceive. Indeed the U.S. National Research Council (Risser et al., 2007) identify noise and shadow flicker as the two key impacts of wind turbines on human health and well-being.

Not all health agencies, however, recognize that sound waves from wind turbines may cause adverse health effects. Following a review of the literature, the Chief Medical Officer of Health for Ontario (2010), concluded

> that while some people living near wind turbines report symptoms such as dizziness, headaches, and sleep disturbance, the scientific evidence available to date does not demonstrate a direct causal link between wind turbine noise and adverse health effects. The sound level from wind turbines at common residential setbacks is not sufficient to cause hearing impairment or other direct health effects, although some people may find it annoying.
>
> Low frequency sound and infrasound from current generation upwind model turbines are well below the pressure sound levels at which known health effects occur. Further, there is no scientific evidence to date that vibration from low frequency wind turbine noise causes adverse health effects.

What specifically is responsible for the illness reported near wind turbines is controversial; while some of this controversy is scientifically valid, some of it is politically motivated (Phillips, 2010).

It is intriguing that not everyone in the same home experiences symptoms, and the symptoms are not necessarily worse for those nearest the turbines. Indeed, the situation may be much more complex than noise and shadow flicker.

[1]Trent University, Peterborough, Ontario, Canada
[2]Bio-Ag Consultants and Distributors, Inc., Wellesley, Ontario, Canada

Corresponding Author:
Magda Havas, Trent University, Environmental and Resource Studies, 1600 West Bank Drive, Peterborough, Ontario [illegible] K9L 7B8
Email: mhavas@trentu.ca

I-21

Why do some people who live near wind turbines become sick while others feel no ill effects? What aspects of wind power generation and distribution are responsible for the health problems? What can be done to minimize adverse human biological and health effects? These are some of the questions addressed in this report.

Wind Turbines Make Waves

What aspects of wind power generation and distribution are responsible for the adverse health effects experienced by those who live near wind turbines?

The short answer to this question is that *wind turbines make waves*. They make pressure waves and electromagnetic waves. The pressure waves (or sound waves) generated by the moving turbines can be heard as noise and/or perceived as infrasound. The electromagnetic waves are generated by the conversion of wind energy to electricity. This conversion produces high-frequency transients and harmonics that result in poor power quality. These high frequencies can flow along the wires (dirty electricity) and along the ground, thereby causing ground current. These four types of waves—noise, infrasound, dirty electricity, and ground current—and shadow flicker are each likely to contribute to ill health among those who live near wind turbines.

Characteristics of Sound Waves and Electromagnetic Waves

Sound waves are longitudinal waves that require a medium for transport. They travel at the speed of sound (340 meters/second) through air and are much slower than electromagnetic waves that travel at the speed of light (300,000,000 meters/second) and can travel through a vacuum. Both sound waves and electromagnetic waves have a frequency (cycles per second) and an intensity (amplitude of the wave).

Frequency refers to the number of waves or cycles per second and is known as pitch for sound. The A above middle C, for example, is set to a frequency of 440 cycles per second (hertz, abbreviated as Hz). The audible range for the human ear is between 20 and 20,000 Hz. Frequencies below 20 Hz are referred to as "infrasound," and, although they cannot be heard, they can still have an effect on the body. Infrasound can travel much greater distances than higher frequency sound waves and could potentially reach and affect a much larger population.

The frequencies of electromagnetic waves, generated by wind turbines, fall within two ranges of the electromagnetic spectrum: extremely low frequency (ELF), below 1,000 Hz; and the lower range (kilohertz [kHz] to megahertz [MHz]) of the radio frequency radiation (RFR) band. Electromagnetic waves can enter homes by various paths: through the air, along wires, through the ground, and via plumbing and other metal structures. Electromagnetic waves travelling across the ground contribute to ground current.

Intensity is measured by the amplitude of the wave and, for sound, is measured in decibels (dB). Vibrations with the same frequency but different amplitude will sound the same, but one will be louder than the other. The decibel scale is logarithmic. A quiet bedroom is at 25 dB, conversation is around 60 dB, a rock group is at 110 dB, and the human threshold of pain is at 140 dB.

The intensity of electromagnetic waves is measured in various ways: electric field, magnetic field, voltage, current, and power density. The biological effects of electromagnetic energy are a function of frequency, intensity, and both the manner and the duration of exposure.

Pressure Waves: Noise

Most people who live near wind turbines and complain of ill effects blame the effects on the noise generated by the turbines (Frey & Hadden, 2007).

> Everything changed . . . when the wind turbines arrived . . . approximately 700 metres away from our property . . . Within days of the windfarm coming into operation we began to hear a terrible noise . . . The noise drove us mad. Gave us headaches. Kept us awake at night. Prevented us from having windows and doors open in hot weather, and was extremely disturbing.
>
> This noise is like a washing machine that's gone wrong. It's whooshing, drumming, constant drumming, noise. It is agitating. It is frustrating. It is annoying. It wears you down. You can't sleep at night and you can't concentrate during the day . . . It just goes on and on . . . It's torture . . . [4 years later] You just don't get a full night's sleep and when you drop off it is always disturbed and only like "cat napping." You then get up, tired, agitated and depressed and it makes you short-tempered . . . Our lives are hell.

The French National Academy of Medicine (Chouard, 2006) issued a report that concludes,

> People living near the towers, the heights of which vary from 10 to 100 meters, sometimes complain of functional disturbances similar to those observed in syndromes of chronic sound trauma . . .
>
> The sounds emitted by the blades being low frequency, which therefore travel easily and vary according to the wind . . . constitute a permanent risk for the people exposed to them . . .
>
> . . . sound levels 1 km from an installation occasionally exceeded allowable limits.
>
> . . . the Academy recommends halting wind turbine construction closer than 1.5 km from residences. (Translated from French)

Noise, especially at night, has been associated with an increase in stress hormones leading to hypertension, stroke, heart failure, and immune problems. It is discussed in greater detail elsewhere in this journal.

Pressure Waves: Infrasound

Repetitive noise can be disturbing, especially at night, when sound seems amplified. However, pressure waves at levels outside the range of human hearing can also have unpleasant side effects.

In Nova Scotia, one family was unable to remain in their home and blamed their loss of sleep and headaches on vibrations from 17 turbines (Keller, 2006).

> The d'Entremont family complained of noise and low frequency vibrations in their house after the wind turbines began operation in May 2005. The inaudible noise deprived his family of sleep, gave his children and wife headaches, and "made it impossible for them to concentrate." They now live nearby; if they return to their home, the symptoms return.
>
> Natural Resources Canada, which oversees funding for wind farm projects, found no problems with low-frequency noise or infrasound. The government report concludes that the measurements:
>
> indicate sound at infrasonic frequencies below typical thresholds of perception; infrasound is not an issue. (cited in Frey & Hadden, 2007)

Gordon Whitehead, a retired audiologist with 20 years of experience at Dalhousie University in Halifax, conducted tests and found similar results but came up with a different conclusion:

> They're [Natural Resources Canada] viewing it from the standpoint of an engineer; I'm viewing it from the standpoint of an audiologist who works with ears . . . The report should read that (the sound) is well below the auditory threshold for perception. In other words, it's quiet enough that people would not be able to hear it. But that doesn't mean that people would not be able to perceive it.
>
> " . . . low-frequency noise can affect the balance system of the ear, leading to a range of symptoms including nausea, dizziness and vision problems. It's not perceptible to the ear but it is perceptible. It's perceptible to people with very sensitive balance mechanisms and that's generally people who get very easily seasick.

Resonance may explain why infrasound is harmful at low intensities. Different parts of the human body have different resonance frequencies. When the external frequency generated by a wind turbine approaches the resonance frequency of a part of the human body, that body part will preferentially absorb the energy and begin to vibrate. For example, frequencies that affect the inner ear (between 0.5 and 10 Hz) can interfere with balance, cause dizziness or vertigo, contribute to nausea, and be experienced as tinnitus or ringing in the ears. According to the International Standards Organization (ISO Standards 2631), frequencies for the eye are between 20 and 90 Hz, head 20 and 30 Hz, chest wall 50 and 100 Hz, abdomen 4 and 8 Hz, and spinal column 10 and 12 Hz. Some of the symptoms documented at infrasonic frequencies (between 4 and 20 Hz) include general feeling of discomfort, problems with breathing, abdominal and chest pain, urge to urinate, lump in throat, effect on speech, and head symptoms (Frey & Hadden, 2007).

According to a report by the U.S. Air Force, Institute for National Security Studies, acoustic infrasound can have dramatic and serious effects on human physiology (Bunker, 1997).

> Acoustic, infrasound: very low frequency sound which can travel long distances and easily penetrate most buildings and vehicles. Transmission of long wavelength sound creates biophysical effects, nausea, loss of bowels, disorientation, vomiting, potential organ damage or death may occur. Superior to ultrasound because it is "inband," meaning it does not lose its properties when it changes mediums such as air to tissue. By 1972 an infrasound generator had been built in France, which generated waves at 7Hz. When activated it made the people in range sick for hours.

In a paper known as "The Darmstadt Manifesto," published in September 1998 by the German Academic Initiative Group and endorsed by more than 100 university professors in Germany, the German experience with wind turbines is described as follows (cited in Frey & Hadden, 2007):

> More and more people are describing their lives as unbearable when they are directly exposed to the acoustic and optical effects of wind farms. There are reports of people being signed off sick and unfit for work, there is a growing number of complaints about symptoms such as pulse irregularities and states of anxiety, which are known to be from the effects of infrasound [sound frequencies below the normal audible limit].

Infrasound is influenced by topography, distance, and wind direction (Rogers, Manwell, & Wright, 2006) and differs from home to home and room to room because each room is a distinct cavity with its own resonant frequency. Whether a door is open or closed can alter the effect.

The biological effects of low-frequency noise (20-100 Hz) and infrasound (less than 20 Hz) are a function of intensity, frequency, duration of exposure, and direction of the vibration.

Wind Turbine Syndrome and Vibroacoustic Disease

Exposure to low-frequency noise and infrasound may produce a set of symptoms that include depression, irritability, aggressiveness, cognitive dysfunction, sleep disorder, fatigue, chest pain/pressure, headaches, joint pain, nausea, dizziness, vertigo, tinnitus, stress, heart palpitations, and other symptoms. Not everyone has the same sensitivity. Those who experience motion sickness (car, boat, plane), get dizzy or nauseous on carnival rides, have migraine headaches, or have eye or ear problems may be particularly susceptible to low-frequency vibrations.

Two different "diseases" have been associated with low-frequency noise exposure and infrasound. They are wind turbine syndrome—coined by Pierpont (2009) in her book by the same name—and vibroacoustic disease (VAD). VAD is a whole-body, systemic pathology characterized by the abnormal proliferation of extracellular matrices and caused by excessive exposure to low-frequency noise (Castelo Branco & Alves-Pereira, 2004). These two "diseases" differ as described by Pierpont (2009).

> Wind Turbine Syndrome, I propose, is mediated by the vestibular system—by disturbed sensory input to eyes, inner ears, and stretch and pressure receptors in a variety of body locations. These feed back neurologically onto a person's sense of position and motion in space, which is in turn connected in multiple ways to brain functions as disparate as spatial memory and anxiety. Several lines of evidence suggest that the amplitude (power or intensity) of low frequency noise and vibration needed to create these effects may be even lower than the auditory threshold at the same low frequencies.
>
> Vibroacoustic Disease, on the other hand, is hypothesized to be caused by direct tissue damage to a variety of organs, creating thickening of supporting structures and other pathological changes. The suspected agent is high amplitude (high power or intensity) low frequency noise. (p. 13)

VAD seems to be dose dependent, with symptoms becoming progressively worse with continued exposure. Three stages have been identified based on 70 aircraft technicians who, presumably, were exposed to much higher intensities of low-frequency noise than those who live near wind turbines (Castelo Branco, 1999, Castelo Branco & Alves-Pereira, 2004).

Stage 1: Mild, 1 to 4 years, slight mood swings, indigestion, heartburn, mouth/throat infections, bronchitis

Stage 2: Moderate, 4 to 10 years, depression, aggressiveness, pericardial thickening, light to moderate hearing impairment, chest pain, definite mood swings, back pain, fatigue, skin infections (fungal, viral, parasitic), inflammation of stomach lining, pain during urination, blood in urine, conjunctivitis, allergies

Stage 3: Severe, more than 10 years, myocardial infarction, stroke, malignancy, epilepsy, psychiatric disturbances, hemorrhages (nasal, digestive, conjunctive mucosa), varicose veins, hemorrhoids, duodenal ulcers, colitis, decrease in visual acuity, headaches, severe joint pain, intense muscular pain, neurological disturbances

Whatever name is given to the symptoms, the symptoms are real and can be caused by low-frequency sound waves and infrasound.

Electromagnetic Waves

One undesirable consequence of wind-generated electricity is poor power quality due to variable weather conditions, mechanical construction of the towers, and the electronic equipment used (Lobos, Rezmer, Sikorski, & Waclawek, 2008). Electricity in North America has a frequency of 60 Hz and is a sine wave when viewed on an oscilloscope (Figure 1). When a wind turbine generates electricity, the frequency must be converted to 60 Hz by power converters; that conversion generates a large spectrum of current and voltage oscillations leading to poor power quality (Lobos et al., 2008). Wind turbines can generate a wide range of frequencies—from less than 1 Hz (Lobos et al., 2008), with the majority of the frequencies in the kHz range associated with power conversion.

Dirty Electricity

High-frequency transient spikes that contribute to poor power quality, also known as dirty electricity, can flow along wires, damage sensitive electronic equipment, and adversely affect human and animal health.

After wind turbines were activated in Ripley, Ontario, several of the residents complained of ill health. Residents suffered from headaches, poor sleep, elevated blood pressure (requiring medication), heart palpitations, itching, ringing and pain in the ears, watering eyes, and pressure on the chest causing difficulty breathing. These symptoms disappear when the residents leave the area. Some residents were forced to move out of their homes because the symptoms were so severe. Locals complain of headaches and poor radio reception when they drive near these power lines.

One of the authors (DC) measured the power quality near several residences where people were unwell. The primary neutral-to-earth voltage (PNEV) is the electrical potential difference between the earth and the neutral wire on the primary distribution line, as shown in Figure 2. Measurements taken before wind turbines were installed and after they were installed and operating (Figure 3) clearly show the distortion (spikes on the waveform) generated by the wind turbines.

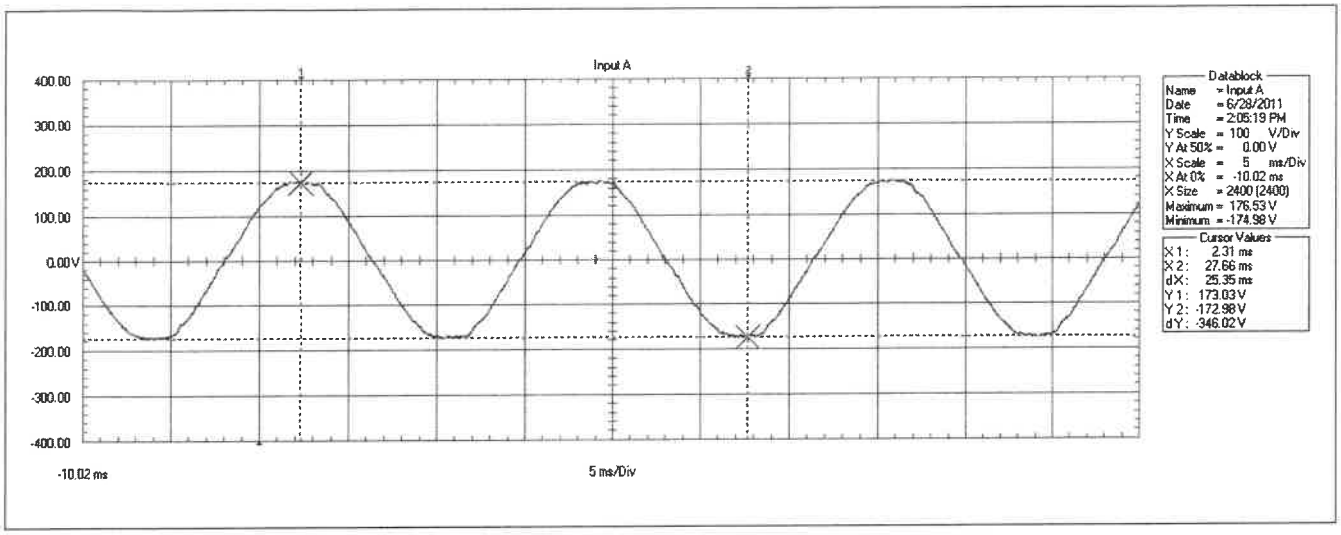


Figure 1. Good power quality exemplified by the 60-Hz sine wave

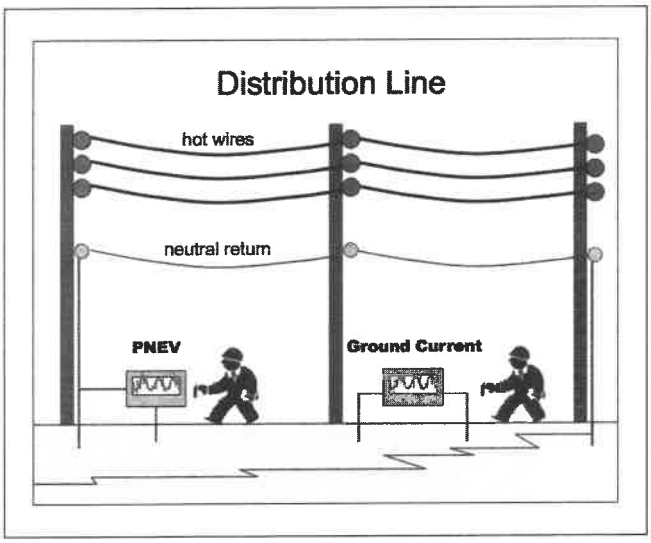


Figure 2. Diagram demonstrating how primary neutral-to-earth voltage (PNEV) and ground voltage measurements are taken

In this area, wind turbines are variable speed and are interconnected. The collection lines connecting the wind turbines to the substation are attached to the same utility pole as the home owners' lines.

According to one of the authors (DC; September 30, 2008),

> We had four families move out of their homes and now if I spend too much time in these homes I get the same symptoms, which is ear aches, ringing in the ears and pressure in the ears. [name removed] eventually buried a portion of the line but have only isolated the lines by insulators so it is better, however there is still some high frequency coming into the houses. The three families that now have buried lines are back in their homes, but things are far from ideal.

Dirty electricity in the kHz range affects human health; this has been shown in schools and homes in both Canada and the United States. Power quality can be improved both on electrical wires by using power line filters (Ontario Hydro, 1998) and inside buildings by using special surge suppressors or power filters that dampen the voltage spikes (http://www.stetzerelectric.com).

In one Wisconsin School that had "sick building syndrome," once power quality was improved, the health of both teachers' and students' improved. According to the school nurse, both staff and students have more energy, fewer allergies, and fewer migraine headaches, and asthmatics rely less on their inhalers (Havas, 2006a).

In a Toronto School, improvements in power quality were accompanied by improvements in teachers' health and students' behavior. Teachers were less tired, less frustrated, less irritable; they had better health and more energy; they had a greater sense of satisfaction and accomplishment; they were more focused and experienced less pain. Students' behavior also improved especially in the elementary grades (Havas, Illiatovitch, & Proctor, 2004). Similar results were reported in a placebo-blinded study in three Minnesota schools (Havas & Olstad, 2008).

Dirty electricity has been associated with increased risk of various types of cancers among teachers in a California school (Milham & Morgan, 2008), with higher blood sugar levels among diabetics, and with exacerbation of tremors and difficulty walking among those with multiple sclerosis (Havas, 2006b). People who are adversely affected by dirty electricity are classified as electrically hypersensitive.

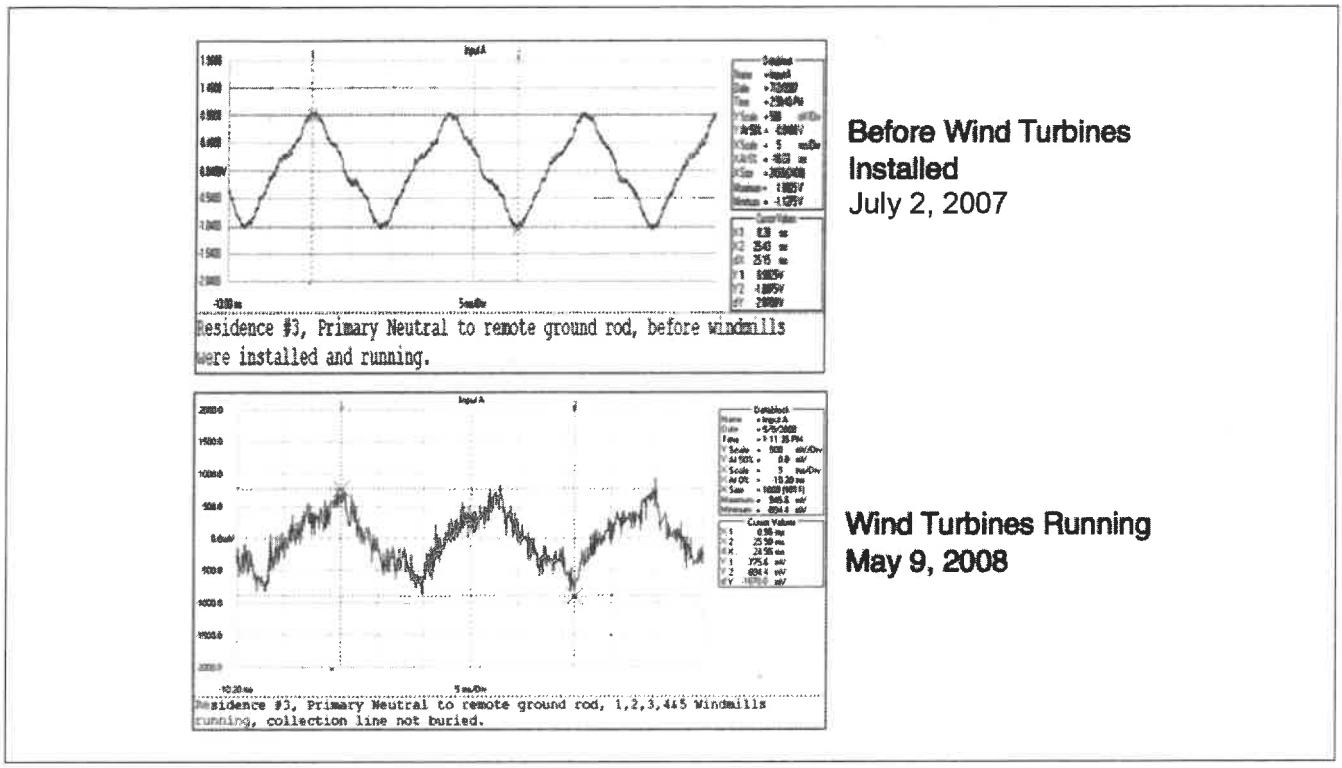


Figure 3. Primary neutral-to-earth voltage (PNEV) at Residence No. 3 in Ripley, Ontario, before wind turbines were installed (July 2, 2007) and when five wind turbines were operating (May 9, 2008)
Note. Collection line was not buried.

Ground Current

Just as dirty electricity can flow along wires, it can also flow along the ground resulting in ground current. Ground current (often measured as voltage and called stray voltage or tingle voltage) is a serious problem in certain locations and has been shown to adversely affect the health of farm families and the health and productivity of farm animals, especially dairy cattle.

The Ontario Federation of Agriculture (2007) provides information on symptoms experienced by farm animals, pets, and people who are exposed to tingle voltage as follows:

> Farmers and their families who suffer from immune disorders such as allergies or rheumatoid arthritis find their symptoms worsen or go into remission in close coordination with livestock symptoms. Periods of fatigue increase. Sleep disorders may increase.
>
> Cats leave the farm, become ill, cease to bear litters or have small, unhealthy litters, or die; coats are usually dull and shaggy and eyes are runny.
>
> Horses may paw the ground and shy away from watering or feeding troughs; behaviour and handling becomes more difficult.
>
> Pigs often take to ear and tail biting; mastitis and baby pig scours are common; piglet mortality may increase.
>
> Cattle lap water from the trough or bowl; feed in the bottom of the manger is not cleaned up; milk out is slow and uneven; cows are reluctant to enter the milk parlour and quick to leave; slow growth in calves and heifers; somatic cell counts are high; unexplained spontaneous abortions of calves; bulls become markedly more irritable.

According to the *National Electrical Safety Code (NESC) Handbook* (Clapp, 1997),

> When the earth returns were used in some rural areas prior to the 1960's, they became notorious offenders in dairy areas because circulating currents often cause both step and touch potentials.
>
> In some cases, they have adversely affected milking operations by shocking the cattle when they were connected to the milking machines, and have affected feeding. (p. 152)

According to Lefcourt (1991) in the U.S. Department of Agriculture book titled *Effects of Electrical Voltage/Current on Farm Animals: How to Detect and Remedy Problems*:

> The effect of a transient voltage superimposed on the regular power voltage (dc or ac) is to cause a momentary

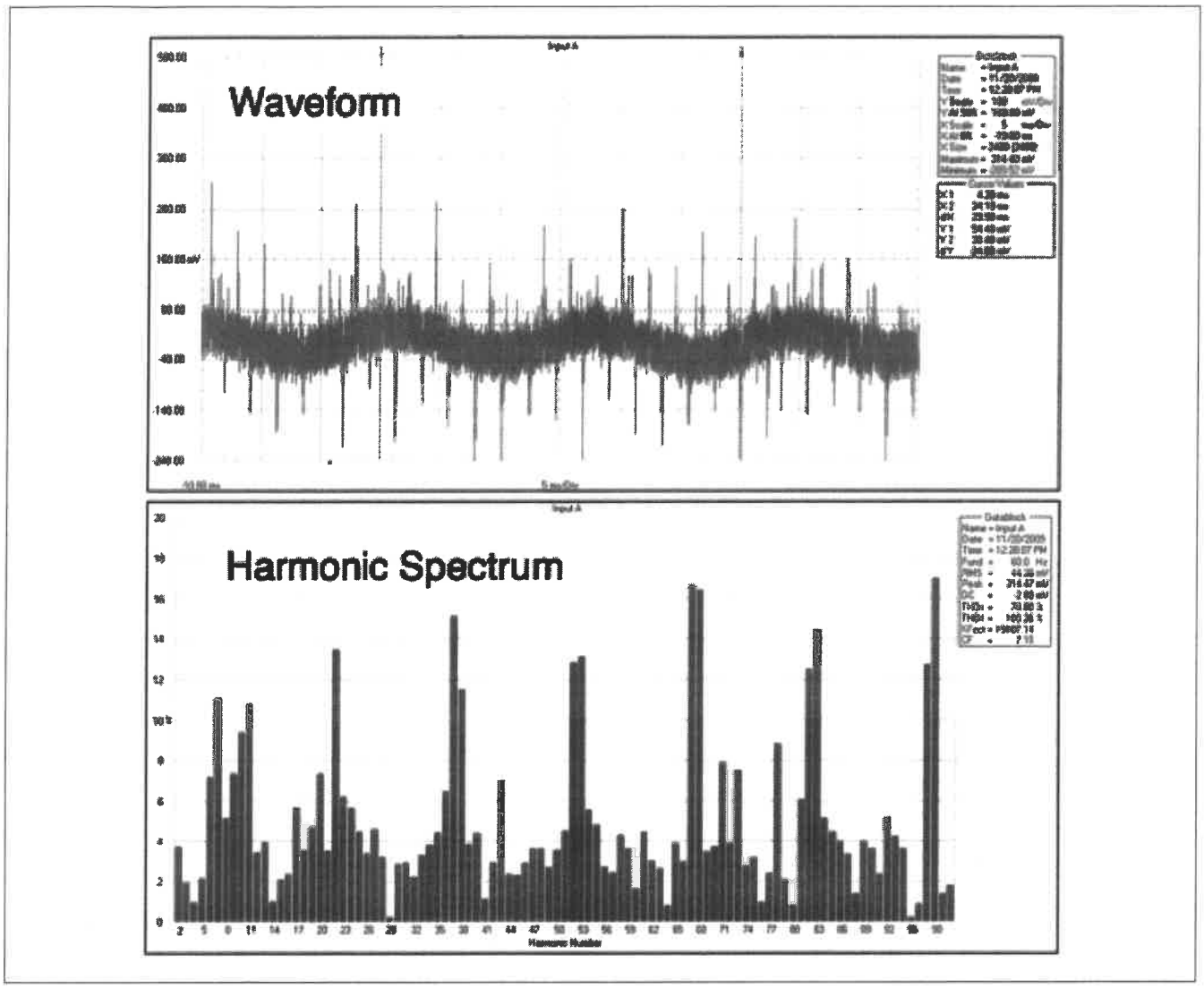


Figure 4. Ground voltage measured at the Palm Springs wind farm in California using 50 feet of copper wire attached to two metal rods in the earth

Note. The top graph shows the distorted 60-Hz waveform, and the bottom graph shows the harmonic frequencies. Data courtesy of Dr. Sam Milham.

> change in the waveform. When the transient causes the momentary voltage to be greater than normal, it may cause a transient current to flow in an animal. If the transient waveform has sufficient energy (magnitude and duration), there may be an animal response. (p. 63-64)

Indeed, dirty electricity flowing along the ground may be more harmful to farm animals than the 60-Hz ground current (Hillman et al., 2003):

> Cows were sensitive to harmonic distortions of step-potential voltage, suggesting that utility compliance with IEEE standards on dairy farms may need to be addressed.
>
> Power quality varied greatly from farm to farm and day to day. Milk production responses to changes in power quality varied inversely with the number of transient events recorded with event recorders, oscilloscope, and power quality meters. Harmonics often gave better estimates of electrical effects on milk production than voltage *per se*. (p. 19)

Do wind turbines generate ground current? They can if proper safeguards are not taken. Generally, this is a problem with power distribution once the energy leaves the turbine.

Figure 4 shows the waveform of ground voltage near an industrial wind farm in Palm Springs, California (as shown in Figure 5 photographs). The waveform distortion in Figure 3 and 4 are considerable when compared with Figure 1.

Figure 5. Wind farm in Palm Springs, California, showing (A) location of ground voltage readings; (B), view of wind turbines from the ground; and (C) view of wind turbines from the air
Note. Photograph A from Dr. Sam Milham. Photographs B and C from Google maps.

Burying the collection line may not eliminate the ground voltage but can improve power quality, as shown in Figure 6.

Just as animals are adversely affected by dirty ground current, so are people. If ground current enters a home via the plumbing, touching any part of the plumbing (e.g., faucet) induces a current in the body, known as contact current.

In one Ripley home, the frequency fingerprint (relative intensities of various frequencies) on the plumbing (sink to floor measurement) was similar to the PNEV, indicating that the source of the ground voltage was the wind turbines' collection line (Figure 7). In this home, the sink to floor contact current was calculated to be 400 microamperes (peak to peak based on 200 millivolts and 500 ohms), and this value is 22 times higher than levels associated with cancer according to Kavet, Zaffanella, Daigle, and Ebi (2000).

> "The absolute (as well as modest) level of contact current modeled (18 micro Amps) produces average electric fields in tissue along its path that exceed 1 mV/m. At and above this level, the NIEHS Working Group [1998] accepts that biological effects relevant to cancer have been reported in "numerous well-programmed studies." (p. 547)

Wertheimer, Savitz, and Leeper (1995) documented the link between ground current and cancer in Denver, Colorado. They found that leukemia risk increased by 300% among children exposed to elevated magnetic field from ground current that enters the home through conductive plumbing.

Electrohypersensitivity (EHS)

Why do some people who live near wind turbines become sick while others feel no ill effects?

Exposure to both pressure waves and electromagnetic waves is highly variable—spatially and temporally—as is sensitivity to these vibrations. Not everyone in the same home is going to have the same exposure or the same sensitivity. People who have balance problems, experience motion sickness, or have ear or eye problems are more likely to react to low-frequency sound vibrations. Those who are electrically hypersensitive are more likely to suffer from dirty electricity

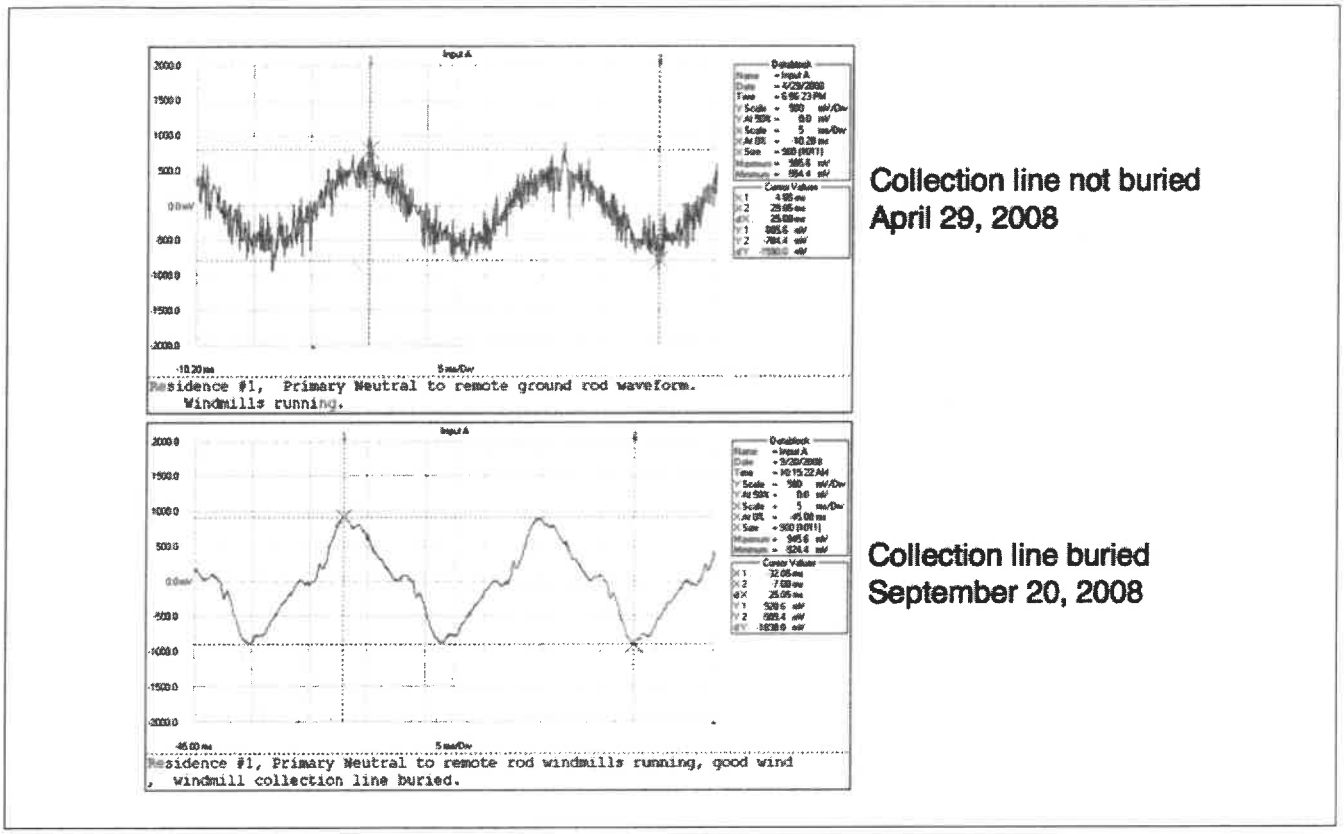


Figure 6. Primary neutral-to-earth voltage (PNEV) at Residence 1 in Ripley, Ontario, when wind turbines were operating
Note. Collection line from wind turbines was buried on September 20, 2008 (bottom graph), but not on April 29, 2008 (top graph).

and contact current. As a result, people living in the same home may have very different sensitivities and may respond differently to these vibrations.

At the Working Group meeting on EMF Hypersensitivity in Prague, the World Health Organization (2004) described electrosensitivity as

> a phenomenon where individuals experience adverse health effects while using or being in the vicinity of devices emanating electric, magnetic, or electromagnetic fields (EMFs).
>
> Whatever its cause, EHS is a real and sometimes a debilitating problem for the affected persons, while the level of EMF in their neighborhood is no greater than is encountered in normal living environments. Their exposures are generally several orders of magnitude under the limits in internationally accepted standards.

Symptoms include cognitive dysfunction (memory, concentration, problem solving); fatigue and poor sleep; body aches and headaches; mood disorders (depression, anxiety, irritability, frustration, temper); nausea; problems with balance, dizziness, and vertigo; facial flushing, skin irritations, and skin rashes; chest pressure, rapid heart rate, and altered blood pressure; ringing in the ear (tinnitus); and nosebleeds. A comprehensive list of the symptoms is provided in Table 1.

In Sweden, EHS is recognized as a functional impairment (not as a disease). Between 230,000 and 290,000 Swedes (about 3% of the Swedish population) may be electrohypersensitive (Johansson, 2006). The number of people complaining of EHS seems to be increasing as is the medication sold to deal with the symptoms of insomnia, pain, fatigue, depression, and anxiety. By 2017, as many as 50% of the population may experience these symptoms (Hallberg & Oberfeld, 2006).

Some individuals may have a predisposition to EHS. Those who have experienced physical trauma to their nervous system (whiplash), electrical trauma in the form of multiple shocks or several severe shocks, and/or chemical exposure to mercury or pesticides are likely to be more electrically sensitive. Children, the elderly, and those with impaired immune systems are also likely to be more electrically sensitive.

It is not possible to determine which factors are contributing to ill health until appropriate monitoring is conducted and steps are taken to reduce exposure to the offending agents. Monitoring of both electromagnetic waves and pressure waves in homes where people report ill health is highly recommended as are the mitigation techniques mentioned below.

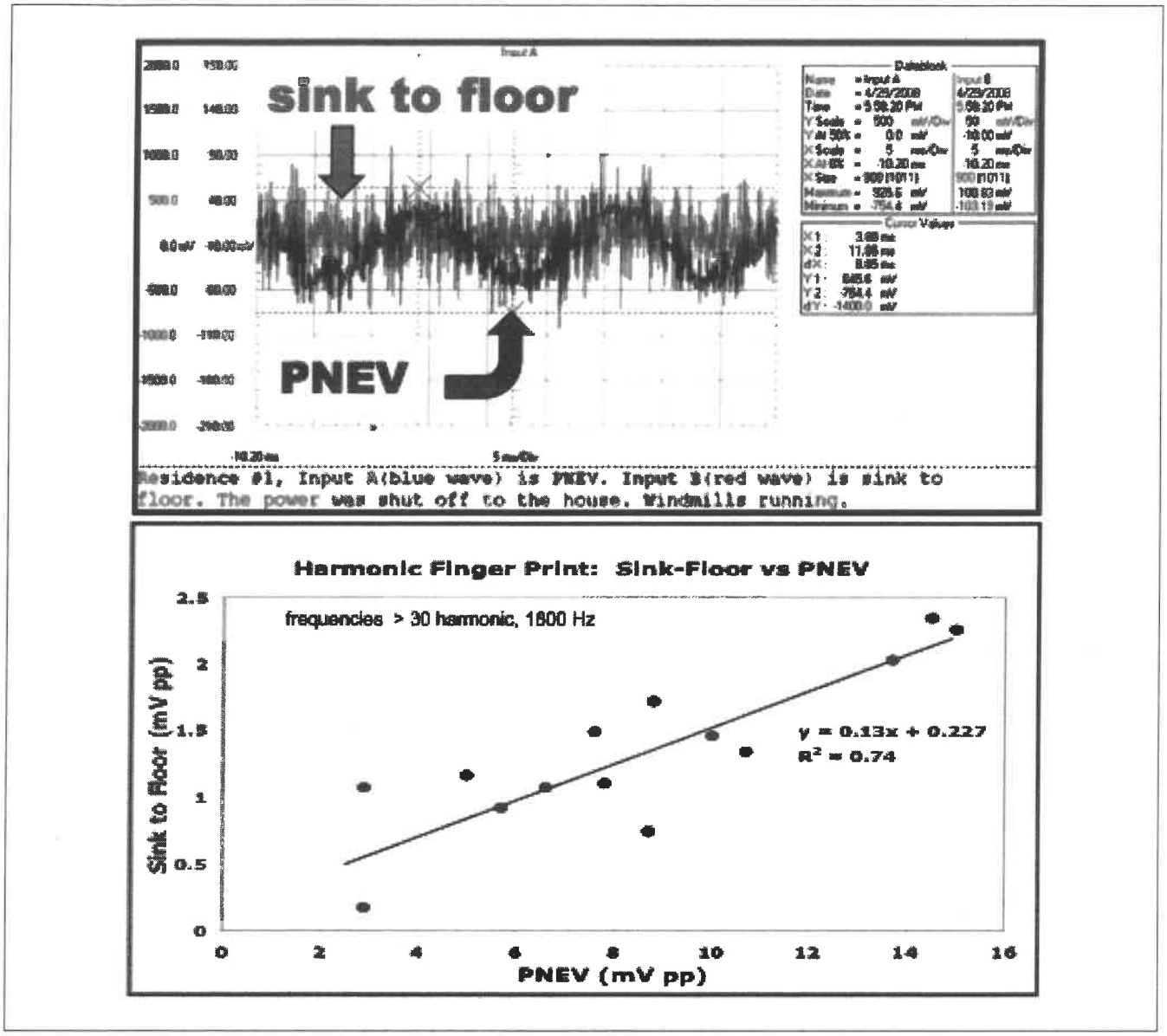


Figure 7. The primary neutral-to-earth voltage (PNEV) and the sink-to-floor voltage for Residence 1 in Ripley, Ontario (top graph), and the harmonic figure print for these voltages (bottom graph).

Recommendations

What can be done to minimize adverse biological and health effects for those living near wind turbines?

One obvious step is to eliminate or reduce exposure to the agent(s) causing the illness.

1. To minimize noise and exposure to infrasound, the following steps should be taken:
   a. Wind turbines should be placed as far away as possible from residential areas. The French National Academy of Medicine (Chouard, 2006) recommends 1.5 km from residential areas.
   b. Buffers can be constructed to disrupt pressure waves and to absorb or deflect sound waves in areas where turbines are closer to homes or where problems have been documented,
2. To improve power quality, the following steps should be taken:
   a. The electricity should be "filtered" at all inverters before it leaves the wind turbine. Ontario Hydro (1998) provides information on power line filters and other ways to improve power quality.
   b. The collector lines from the wind turbines should be attached to utility poles that do not provide power to homes.
   c. Power from the substation supplied by the wind turbines should be filtered before it is distributed to customers.

Table 1. Comprehensive List of Electrohypersensitivity (EHS) Symptoms (Bevington, 2010)

Auditory	Dermatological	Musculoskeletal	Ophthalmologic
earaches, imbalance, lowered auditory threshold, tinnitus	brown 'sun spots', crawling sensations, dry skin, facial flushing, growths & lumps, insect bites & stings, severe acne, skin irritation, skin rashes, skin tingling, swelling of face/neck	aches / numbness pain / prickling sensations in: bones, joints & muscles in: ankles, arms, feet legs, neck, shoulders, wrists, elbows, pelvis, hips, lower back, cramp / tension in: arms, legs, toes, muscle spasms, muscular paralysis, muscular weakness, pain in lips, jaws, teeth with amalgam fillings, restless legs, tremor & shaking	eyelid tremors/'tics', impaired vision, irritating sensation, pain / 'gritty' feeling, pressure behind eyes, shiny eyes, smarting, dry eyes
Cardiovascular	**Emotional**		**Other Physiological**
altered heart rate, chest pains, cold extremities especially hands & feet, heart arrhythmias, internal bleeding, lowered/raised blood pressure, nosebleeds, shortness of breath, thrombosis effects	anger, anxiety attacks, crying, depression, feeling out of control, irritability, logorrhoea, mood swings,		abnormal menstruation, brittle nails, hair loss, itchy scalp, metal redistribution, thirst / dryness of lips, tongue, eyes
Cognitive	**Gastrointestinal**	**Neurological**	**Respiratory**
confusion, difficulty in learning new things, lack of concentration, short / long-term memory impairment, spatial disorientation	altered appetite, digestive problems, flatulence, food intolerances	faintness, dizziness, 'flu-like symptoms, headaches, hyperactivity, nausea, numbness, sleep problems, tiredness	asthma, bronchitis, cough /throat irritation, pneumonia, sinusitis
	Genito-urinary smelly sweat / urine, urinary urgency, bowel urgency		**Sensitisation** allergies, chemical sensitivity, light sensitivity, noise sensitivity, smell sensitivity

d. Wind power electrical substations that require power from an external source (electrical distribution network) must ensure that the power quality of this eternal source is not affected as this can result in power quality problems for customers connected to the same external power source.
e. Nearby home owners may need to install power line filters in their homes if levels of dirty electricity remain high.

3. To reduce ground current/voltage, the following steps should be taken:
   a A proper neutral system (possibly a five-wire system) should be installed to handle the high-frequency return current in overhead lines (Electric Power Research Institute, 1995).
   b. Insulators can be placed between the neutral line and the grounding grid for the wind turbine.
   c. The collection lines from the wind turbine to the substation should be buried if the other techniques to minimize dirty ground current are ineffective.
   d. Local home owners may need to install stray voltage isolators near their transformers until the electric utility can resolve the problem (Hydro One, 2007).

If these steps are taken, improved quality of life and a feeling of wellness may return to some of the people adversely affected by nearby wind turbines.

Conclusions

A subset of the population living near wind turbines is experiencing symptoms of ill health. These symptoms are likely caused by a combination of noise, infrasound, dirty electricity, ground current, and shadow flicker. These frequencies can be highly viable spatially and temporally and are affected by distance; terrain; wind speed and direction; shape, size, and type of dwelling; type of power converters used; state of the electrical distribution line; type and number of grounding systems; and even the type of plumbing in homes. Furthermore, not everyone has the same sensitivity to sound and electromagnetic radiation nor do they have the

same symptoms. The following symptoms seem to be quite common: sleeplessness, fatigue, pain, dizziness, nausea, mood disorders, cognitive difficulties, skin irritations, and tinnitus. To help alleviate symptoms in areas where wind turbines have been erected, remediation is necessary to reduce or eliminate both sound waves and electromagnetic waves. More research is required to help us better understand the relative importance of the various factors contributing to poor health. This type of information will enable a healthy coexistence between wind turbines and the people living nearby.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

References

Bevington, M. (2010). *Electromagnetic-sensitivity and electromagnetic-hypersensitivity: A summary*. London, England: Capability Books.

Bunker, R. J. (Ed.). (1997). *Nonlethal weapons: Terms and references* (INSS Occasional Paper No. 15). Colorado Springs, CO: USAF Institute for National Security Studies. Retrieved from http://www.aquafoam.com/papers/Bunker.pdf

Castelo Branco, N. A. (1999). The clinical stages of vibroacoustic disease. *Aviation, Space, and Environmental Medicine, 70*(3, Pt. 2), A32-A39.

Castelo Branco, N. A., & Alves-Pereira, M. (2004). Vibroacoustic disease. *Noise & Health, 6*(23), 3-20.

Chouard, C.-H. (2006). Le retentissement du fonctionnement des eoliennes sur la sante de l'homme [Repercussions of wind turbine operations on human health]. *Panorama du medecin*. Retrieved from http://ventdubocage.net/documentsoriginaux/sante/eoliennes.pdf

Chief Medical Officer of Health. (2010). *The potential health impact of wind turbines*. Retrieved from http://www.health.gov.on.ca/en/public/publications/ministry_reports/wind_turbine/wind_turbine.pdf

Clapp, A. L. (Ed.). (1997). *NESC handbook: A discussion of the national electrical safety code* (4th ed.). New York, NY: Institute for Electrical and Electronic Engineers.

Electric Power Research Institute. (1995). *Handbook for the assessment and management of magnetic fields caused by distribution lines* (EPRI Report TR-106003). Palo Alto, CA: Author.

Frey, B. J., & Hadden, P. J. (2007). *Noise radiation from wind turbines installed near homes: Effects on health–With an annotated review of the research and related issues*. Retrieved from http://docs.wind-watch.org/wtnoisehealth.pdf

Hallberg, O., & Oberfeld, G. (2006). Letter to the editor: Will we all become electrosensitive? *Electromagnetic Biology and Medicine, 25*, 189-191.

Havas, M. (2006a, November). *Dirty electricity: An invisible pollutant in schools [Feature Article]. Education Forum*. Retrieved from http://www.dirtyelectricity.ca/images/Dirty%20Electricity%20in%20schools.pdf

Havas, M. (2006b). Electromagnetic hypersensitivity: Biological effects of dirty electricity with emphasis on diabetes and multiple sclerosis. *Electromagnetic Biology and Medicine, 25*, 259-268.

Havas, M., Illiatovitch, M., & Proctor, C. (2004, October). *Teacher and student response to the removal of dirty electricity by the Graham/Stetzer filter at Willow Wood school in Toronto, Canada*. Paper presented at the 3rd International Workshop on Biological Effects of EMFs, Kos, Greece.

Havas, M., & Olstad, A. (2008). Power quality affects teacher well-being and student behavior in three Minnesota Schools. *Science of the Total Environment, 402*, 157-162.

Hillman, D., Stetzer, D., Graham, M., Goeke, C. L., Matthson, K. E., VanHorn, H. V., & Wilcox, C. J. (2003, July). *Relationship of electric power quality to milk production of dairy herds*. Paper presented at the Society for Engineering in Agricultural, Food and Biological Systems, Las Vegas, NV.

Hydro One. (2007). *Stray voltage solutions guide for electrical contractors*. Retrieved from http://www.hydroone.com/MyBusiness/MyFarm/Documents/SVSolutionsGuideforElectrical_Contractors.pdf

Johansson, O. (2006). Electrohypersensitivity: State-of-the-art of a functional impairment. *Electromagnetic Biology and Medicine, 25*, 245-258.

Kavet, R., Zaffanella, L. E., Daigle, J. P., & Ebi, K. L. (2000). The possible role of contact current in cancer risk associations with residential magnetic fields. *Bioelectromagnetics, 21*, 538-553.

Keller, J. (2006, November 13). Nova Scotians flee home, blame vibrations from 17 turbines for loss of sleep, headaches. *Toronto Star*. Retrieved from http://www.ventdecolere.org/archives/nuisances/noise%26low_frequency.pdf

Lefcourt, A. M. (Ed.). (1991). *Effects of electrical voltage/current on farm animals: How to detect and remedy problems* (Agriculture Handbook No. 696). Washington, DC: U.S. Department of Agriculture.

Lobos, T., Rezmer, J., Sikorski, T., & Waclawek, Z. (2008). Power distortion issues in wind turbine power systems under transient states. *Turkish Journal of Electrical Engineering & Computer Sciences, 16*, 229-238.

Milham, S., & Morgan, L. L. (2008). A new electromagnetic exposure metric: High frequency voltage transients associated with increased cancer incidence in teachers in a California school. *American Journal of Industrial Medicine, 51*, 579-586.

Ontario Federation of Agriculture. (2007). *Fact sheet: Identifying tingle voltage*. Retrieved from http://www.wlwag.com/uploads/5/2/9/6/5296281/tinglevoltage.pdf

Ontario Hydro. (1998). *Power quality: Reference guide* (6th ed.). Toronto, Ontario, Canada: Author.

Phillips, C. V. (2010, July 3). *An analysis of the epidemiology and related evidence on the health effects of wind turbines on local residents*. Retrieved from http://www.wind-watch.org/documents/analysis-of-the-epidemiology-and-related-evidence-on-the-health-effects-of-wind-turbines-on-local-residents/

Pierpont, N. (2009). *Wind turbine syndrome: A report on a natural experiment*. Santa Fe, NM: K-Selected Books.

Risser, P., Burke, I., Clark, C., English, M., Gauthreaux, S., Jr., Goodman, S., & Whitmore, R. (2007). *Environmental impacts of wind-energy projects*. Washington, DC: National Academies Press.

Rogers, A. L., Manwell, J. F., & Wright, S. (2006). *Wind turbine acoustic noise* (White paper). Amherst: University of Massachusetts.

Wertheimer, N., Savitz, D. A., & Leeper, E. (1995). Childhood cancer in relation to indicators of magnetic fields from ground current sources. *Bioelectromagnetics*, *16*, 86-96.

World Health Organization. (2004, October). WHO International seminar and working group meeting on EMF hypersensitivity, Prague, Czech Republic.

Bios

Magda Havas, PhD, is an associate professor at Trent University where she teaches and conducts research on the biological and health effects of electromagnetic and chemical pollutants. She received her BSc and PhD at the University of Toronto and did postdoctoral research at Cornell University on acid rain and aluminum toxicity.

David Colling has applied his electrical engineering studies at Ryerson Polytechnical Institute and his specialized training in electrical pollution to conduct electrical pollution testing for Bio-Ag on farms, homes, and office buildings. Some of the homes tested are located in the environs of industrial wind turbines.

Scientific Research Publishing

Open Journal of Social Sciences, 2017, 5, 80-107
http://www.scirp.org/journal/jss
ISSN Online: 2327-5960
ISSN Print: 2327-5952

Environmental Noise Pollution: Has Public Health Become too Utilitarian?

Noise
Sleep interference
Precautionary Princ

Alun Evans

Centre for Public Health, Queen's University Belfast, Belfast, UK
Email: a.evans@qub.ac.uk

How to cite this paper: Evans, A. (2017) Environmental Noise Pollution: Has Public Health Become too Utilitarian? *Open Journal of Social Sciences*, **5**, 80-107.
https://doi.org/10.4236/jss.2017.55007

Received: March 16, 2017
Accepted: May 9, 2017
Published: May 12, 2017

Abstract

Environmental noise pollution is an ever-increasing problem. The various sources: Aircraft, Road Traffic and Wind Farms are reviewed, but the latter source, because of the intrusive, impulsive and incessant nature of the sound emitted, is the major focus of this review. Wind turbines produce a range of sound but it is the Infrasound and low frequency noise which deserves special attention. Infrasound is considered to be below the range of human hearing so it is not measured in routine noise assessments in the wind farm planning process. There is, however, evidence that many can register it and a sizeable minority is sensitive, or becomes sensitised to it. The actual route of transmission still requires elucidation. The net effect of the entire range of noise produced is interference with sleep and sleep deprivation. Sleep, far from being a luxury is vitally important to health and insufficient sleep, in the long term, is associated with a spectrum of diseases, particularly Cardiovascular. The physiological benefits of sleep are reviewed, as is the range of diseases which the sleep-deprived are predisposed to. Governments, anxious to meet Green targets and often receiving most of their advice on health matters from the wind industry, must commission independent studies so that the Health and Human Rights of their rural citizens is not infringed. Public Health, in particular, must remember its roots in Utilitarianism which condoned the acceptance of some *Collateral Damage* provided that the greatest happiness of the greatest number was ensured. The degree of *Collateral Damage* caused by wind farms should be totally unacceptable to Public Health which must, like good government, fully exercise the *Precautionary Principle*. The types of study which should be considered are discussed. Indeed, the father of Utilitarian Philosophy, Jeremy Bentham, urged that government policy should be fully evaluated.

Keywords

Environmental Noise Pollution, Wind Farms, Infrasound, Health Impacts,

DOI: 10.4236/jss.2017.55007 May 12, 2017

I-22

Public Health, Utilitarianism, Collateral Damage, Precautionary Principle

1. Introduction

There are a number of emerging threats to Public Health, and some of these can be directly ascribed to human activity, chief among which are Global Warming, air pollution and environmental noise pollution. This paper will concentrate on the issue of environmental noise pollution and examine how modern Public Health has lived up to its responsibilities in controlling it. Over a century ago, the Nobel Prize-winning microbiologist, Robert Koch, predicted [1] "One day man will have to fight noise as fiercely as cholera and pest (plague)." The accuracy of this prediction is attested to by the statement [2] from the United States Environmental Protection Agency that, "The over-all loudness of environmental noise has been doubling every ten years in pace with social and industrial growth, and, if allowed to continue unchecked, the cost of alleviating it in the future may be insurmountable." Perhaps surprisingly, this statement is more than 40 years old, yet the problem has been growing, unchecked, ever since.

From an evolutionary perspective, an awareness of sound is essential to alert us of incipient danger, but our aural acuity may have left us vulnerable to when it is present in excess. The earliest problems arose with the introduction of noisy industrial processes a couple of centuries ago, which induced deafness [3]. We are now being bombarded with noise pollution from diverse sources, which predisposes us to a range of diseases. Light radiation ranges from Ultraviolet to Infrared, and apart from its intensity, its wavelength will determine its effect on the receiver: typically different wavelengths in the Ultraviolet range have different effects on our skin [4]. Similarly, it is not just the amplitude of noise which brings health consequences, but also, its "frequency content" (considering the sound as a stimulus rather than how frequency in the audible range is perceived as pitch).

Sound is caused by a series of pressure pulsations, or more broadly, by changes in air pressure. The spectrum of sound [4] frequency ranges from >1 to more than 20,000 cycles per second or Hz, with the range up to 20 Hz classified [5] as Infrasound, >20 - 200 Hz as low frequency sound (the lowest note on a piano has a frequency of 33 Hz and Middle C, 262 Hz [6]), >200 - 20,000 Hz as the human auditory range, and >20,000 Hz as Ultrasound. Strictly, pressure pulsations outside our auditory range cannot be described as sound but they are still able to exert an effect on us [5].

As with light, sound's effects on human health are not only determined by its intensity, or amplitude, but also by its frequency and the rate of change in amplitude. The term Infrasound is confusing, because how could sound which we are unable to hear have an effect on us? Perhaps a better way to look at it would be in terms of pressure pulsations. There is increasing evidence that Infrasound is perceived by the brain [7], and possibly by other sensory systems' vibratory

receptors [8]: in the vestibular organ of balance, skin and joints, rather than by those transmitting auditory sensation [7]. Another problem with noise in the lower registers is that it persists longer, travels further and, thanks to diffraction, can turn corners [6].

This, from another evolutionary perspective, is no surprise. Many of our fellow mammals use Infrasound extensively for communication: e.g., giraffes, rhinoceroses, whales and elephants—the latter are capable of sensing distant thunderstorms, because of the Infrasound the storms emit, from over a hundred kilometres away [9], and set off in that direction in the knowledge that they will find water and green vegetation to consume. Humans carry a large range of genes which were acquired in our evolutionary past, but which are now redundant. Sometimes however, these are expressed, for example when, occasionally, someone grows a tail [10]. Olfactory receptor (OR) genes provide a good example of genes which humans possess but do not express. Mammals have over 1000 OR genes and these constitute the largest mammalian gene superfamily. In humans about 60% of these are pseudogenes and have been annulled through mutation [11]. In other primates, the pseudogene rate is about half of this. It is postulated that reduced chemosensory dependence in man drives this OR gene disruption. Individual differences in gene-expression might also explain why a small, but significant, proportion of the population may be more sensitive to the effects of Infrasound than others, and to noise in general [7]. An alternative hypothesis is that sufferers have been "sensitized" through past exposure [5], although both factors could contribute.

This review will concentrate on the adverse health effects associated with environmental noise, particularly those due to the Infrasound and low frequency noise emitted by industrial wind turbines. Some of the adverse health effects are due to sleep deprivation, and the evidence linking it to several diseases, particularly cardiovascular, will be discussed. The control of wind farm noise emissions, and its effectiveness, will be reviewed along with the appropriateness of the Guidelines governing noise limits, and where wind farms are sited. The studies which need to be mounted will then be described. The history of Public Health will be discussed, including the seminal role that Utilitarian Philosophy (the greatest happiness of the greatest number) played in its inception. The response of Public Health to new health threats will be evaluated in the light of the concepts of *Collateral Damage* and the *Precautionary Principle*. The overall aim is to evaluate the adverse health effects of industrial wind turbines and the adequacy of the Public Health response to the problems arising. In particular, the adequacy of the protection of the Health and Human Rights of rural citizens whose health is compromised by wind turbines will be scrutinized.

2. Literature Review

2.1. Extent of the Problem

The problem of noise pollution has been justly highlighted in two recent World Health Organisation reports. The first of these, entitled 'Night Noise Guidelines

for Europe', stated [12] that "... environmental noise is emerging as one of the major Public Health concerns of the twenty-first century." It observed that, "Many people have to adapt their lives to cope with the noise at night," and that the young and the old are particularly vulnerable. This is because hearing in young people is more acute and, in older people, a loss of hearing of higher sound frequencies renders them more susceptible to the effects of low frequency noise [13]. A more recent World Health Organisation report calculated [14] that more than a million healthy life years (Disability Adjusted Life Years) are lost due to environmental noise annually in western EU member states. The vast bulk of these are lost because of noise-induced sleep disturbance, followed by 'Annoyance.' This is a construct assembled from subjects' responses to a questionnaire, where subjects are asked to indicate their 'Level of Annoyance' on a scale [15]. Annoyance is a common finding reported in a population exposed to environmental noise. It is difficult to define accurately, but one authority maintains that it can result from noise interfering with daily activities, feelings, thoughts, sleep or rest, and might be accompanied by negative responses, such as anger, displeasure, exhaustion and stress-related symptoms [16]. It clearly is not a trivial state.

Sleep disturbance is serious if it leads to sleep deprivation [17], which is associated with a gamut of Cardiovascular Diseases (CVD), obesity, diabetes, and poor memory consolidation [1]. In an up-to-date meta-analysis of 160,867 subjects, in whom 11,702 cases occurred, insomnia symptoms were shown to be significantly associated with the risk of cardio-cerebral vascular events [18]; and even some cancers [19]. On top of this, inadequate sleep in children is associated with impaired memory and learning, poor cognitive function, mental health disorders, and obesity [20]. The mechanism for this is not well understood but it may be connected to higher levels of a cannabis-like chemical found in individuals who are deprived of sleep [21]. The latter is of concern because it tends to sow the seeds for diabetes and CVD in later life.

2.2. Importance of Sleep

There is an ever-mounting volume of research to show that sleep is essential for the brain and the physiological well-being of the entire body. Sleep deprivation interferes with learning, causing memory impairment because memory is laid down and reinforced during both the Slow Wave and Rapid Eye Movement phases of sleep. In mice, it has been shown that sleep plays a key role in promoting learning-dependent synapse formation and maintenance on selected dendritic branches, which contribute to memory storage [22]. There are a number of other adverse effects associated with sleep deprivation. Tired individuals are more likely to have road traffic accidents and injure themselves while operating machinery. During sleep, neurotoxins are removed from the brain [23]. Lately, an association between sleep deprivation and loss of brain volume has been demonstrated [24]. This study was based on serial MRI scans carried out in 147 community-dwelling adults. In addition, it has been demonstrated [25] that

various inflammatory biomarkers are affected by sleep deprivation.

Sleep deprivation produced experimentally also very rapidly alters the expression in a wide range of genes, involving several body systems [26] [27]. This could explain the links between sleep deprivation and CVD where the putative intermediate risk factors include blood pressure, clotting factors, blood viscosity, and blood lipids and glucose [1]. The cardiovascular effects of environmental noise exposure have been reviewed recently in studies carried out in 11 countries. These compared aircraft, road and railway sources of noise: aircraft noise was identified as the most highly annoying, and railways the least [1]. It is unclear as to which frequencies are contributing most because very often the full acoustic spectrum is not assessed. Jet aircraft, in particular, produce Infrasound and low frequency noise in abundance, so people dwelling near airports suffer adverse health effects [28] [29].

Why has environmental noise pollution become such a problem? Air and road traffic have increased and industrial installations have tended to get bigger. There are noise limits set, but they may not always be enforced. The other aspect, which should be of great concern to Public Health, is that the cut-points established as safe for any factor whose risk is continuously distributed, are nearly always set too high—e.g., blood pressure and LDL cholesterol—and subsequently have to be revised downwards. Asbestos is a prime example, with the permitted level of asbestos being successively reduced over many years [30] until its use was banned in most developed countries. Airports invariably have night time restrictions on flying and road traffic noise tends to be less at night. Wind farms emit noise, sometimes for days on end, and this is a problem because they are being constructed in rural areas where background noise is low. It is a particular problem at night, because Infrasound persists long after the higher frequencies have been dissipated [6]. This paper will concentrate on the health effects of wind turbine noise, which has been shown [31] to be particularly troublesome because of its impulsive, intrusive and incessant nature.

2.3. Health Effects of Wind Turbine Noise

The major adverse health effects caused by wind turbines seem to be due to sleep disturbance and deprivation, with the main culprits identified as loud noise in the auditory range and low frequency noise, particularly Infrasound. This is inaudible in the conventional sense, and is propagated over large distances and penetrates the fabric of dwellings, where it may become amplified by resonance. A report [32] commissioned by the Scottish Government, which is investing in wind energy to a heroic degree, grudgingly accepts that wind turbine noise interferes with sleep. A recent Swedish study, conducted [33] on healthy volunteers in a sleep laboratory, has shown that the noise produced by wind turbines, particularly low frequency band amplitude modulation, is disruptive to sleep. This was indicated by an increase in electro-physiological awakenings, lighter sleep with more wakefulness, and reduced deep sleep and Rapid Eye Movement sleep.

A recent review identified [34] 146 potential papers assessing the effects of wind turbine noise, and after applying stringent criteria, came up with a shortlist of 18, of which eight were included in a meta-analysis. All studies were cross-sectional and a meta-analysis of six of these (n = 2364) revealed that the odds of being annoyed are significantly increased by wind turbine noise (OR: 4.08; 95% CI: 2.37 to 7.04; $p < 0.00001$). The odds of sleep disturbance were also significantly increased with greater exposure to wind turbine noise (OR: 2.94; 95% CI: 1.98 to 4.37; $p < 0.00001$). Four studies reported that wind turbine noise significantly interfered with Quality of Life. Furthermore, the visual perception of wind turbine generators was associated with a greater frequency of reported negative health effects. Visual perception and sound emissions (effects of emissions after propagation on the environment) are directly related to distance so studies need to carefully differentiate the two sources of annoyance to ensure that each is properly assessed.

Sleep deprivation has also been shown [35] to be associated with heart failure in the HUNT Study. The data are quite robust as they are based on 54,279 Norwegians free of disease at baseline (men and women aged 20 - 89 years). A total of 1,412 cases of heart failure developed over a mean follow-up of 11.3 years. A dose-dependent relationship was observed between the risk of disease and the number of reported insomnia symptoms: i) difficulty in initiating sleep; ii) difficulty in maintaining sleep; and iii) lack of restorative sleep. The Hazard Ratios were "0" for none of these; "0.96" for one; "1.35" for two; and, "4.53" for three; this achieved significance at the 2% level. This means that such a result could occur once by chance if the study were to be repeated 50 times. Significance is conventionally accepted at the 5% level.

Another important, recent study is MORGEN, which followed [36] nearly 18,000 Dutch men and women, free of CVD at baseline, over 10 - 14 years. In this period there were 607 events: fatal CVD, non-fatal Myocardial Infarction and Stroke. Adequate sleep, defined as at least seven hours a night, was a protective factor which augmented the benefits conferred by the absence of four traditional cardiovascular risk factors. For example, the benefit of adequate sleep equalled the protective contribution of not smoking cigarettes. Given that cigarette smoking is such a potent risk factor for CVD, this result is striking. The findings built on earlier ones from the MORGEN study [37]. It seems that adequate sleep is important in protecting against a range of CVDs which result when arteries of different sizes are compromised: large (coronary, cerebral) arteries in heart attacks and stroke, small arteries (arterioles) in heart failure. The mechanisms are obscure, but it is known, for example, that exposing mice to stress activates [38] hematopoietic stem cells, *i.e.* affects the immune system and accelerates atherosclerosis.

All of these studies share the weakness that they are "observational" as opposed to "experimental" and, as such, their results do not constitute "proof". The results from the experimental study of sleep deprivation of fairly short durations [26], which affected the expression of a large range of genes, sheds light on the

"Wind Turbine Syndrome (WTS)", a cluster of symptoms which includes sleep disturbance, fatigue, headaches, dizziness, nausea, changes in mood and inability to concentrate [39]. In this condition, Infrasound is a likely causal agent. Another report from HUNT has examined insomnia in almost 25,000 persons and has demonstrated [40] it to be a robust risk factor for incident physical and mental disease, which included several features of WTS.

This group has now shown, in another small intervention study, that mistimed sleep desynchronized from the central circadian clock has a much larger effect on the circadian regulation of the human transcriptome (*i.e.*, a reduction in the number of circadian transcripts from 6.4% to 1% and changes in the overall time course of expression of 34% of transcripts). This may elucidate the reasons for the large excess of cardiovascular events associated with shift work [27]. The results demonstrate that any interference in normal sleeping patterns is inimical to cardiovascular health.

The old admonition that "What you can't hear won't harm you" sadly isn't true. It is now known [41] that the organ of Corti in the cochlea (inner ear) contains two types of sensory cells: one row of inner hair cells which are responsible for hearing; and three rows of outer hair cells which are more responsive to low frequency sound. Another function of the outer hair cells is that, due to their extensibility, they can modify the sensitivity of the cochlea. This has relevance to low frequency hearing and also to detecting higher frequencies which are amplitude-modulated at lower, if not infrasonic, frequencies. The Infrasound produced by wind turbines is transduced by the outer hair cells and transmitted to the brain by Type II afferent fibres. The purpose is unclear as it results in sleep disturbance. This may well be the group which is also liable to travel sickness, which is a sizeable proportion of the population. Schomer and his colleagues have since advanced [42] the theory that as wind turbines increase in size they increasingly emit Infrasound with a frequency below 1 Hz (CPS). Below this frequency the otoliths in the inner ear respond in an exaggerated way in a susceptible minority who will suffer symptoms of WTS. Previously it was thought that the brain was only under the control of electrical and biochemical stimuli, but there is new evidence [43] that it is sensitive, in addition, to mechanical stimuli.

There were important studies carried out in the 1980s which appear to have been forgotten and which give a clue to the mechanisms involved. Danielsson and Landström carried out [44] a study in 20 healthy male volunteers who were bombarded with Infrasound for varying periods. Just 30 minutes' bombardment with 125 dB at 16 Hz resulted in a mean 8 mm increase in diastolic blood pressure. On the other hand, systolic BP was not affected, whereas the Pulse Pressure decreased. This could have important effects in those exposed to environmental Infrasound, for although the intensity may not be profound, chronic exposure might raise blood pressure a little. From a population perspective, this could raise the burden of CVD. Scientists at the University of Toronto Institute for Aerospace and the University of Waterloo found [45] variability in response in

volunteers exposed to Infrasound under laboratory conditions using Infrasound of 8 Hz. The adverse responses of some individuals closely resembled motion sickness. They postulated that individual differences in the reaction to Infrasound might be explained by variability of inner-ear structure or central adaptive mechanisms.

As far back as 1996, the International Standards Organisation acknowledged [46] that motion sickness arises from low frequency oscillatory motion below 1 Hz. The report cites: "...a range of microscopic organs (mechano-receptors) distributed in the living tissues throughout the body that variously signal changing pressure, tension, position, vibratory motion, etc." This is highly intriguing as it seems extremely plausible that the same effect obtains for Infrasound in the same frequency range and this requires urgent clarification. Indeed, the incidence of motion sickness can be predicted from the magnitude, frequency, and duration of vertical oscillation [47]. There is also mounting evidence that jet engine Infrasound can induce Vibro-acoustic Disease [48]. It is recognized [49] that around 15% - 20% of individuals are seriously affected by the Infrasound and low frequency noise produced by aircraft, particularly jets.

A recent economic assessment of US environmental noise as a cardiovascular health hazard suggested that a reduction of 5 dB would reduce hypertension by 1.4% and coronary heart disease by 1.8%, with an annual economic benefit of USD3.9 billion. The threshold for the noise-exposed group was >55 dBA LDN, though there is evidence in the literature that there may be important impacts at even lower levels of noise exposure [50]. Invariably in assessing noise exposure the average sound levels are assessed, whereas it may be that it is the peaks of sound which do the damage. In a study of seals kept in captivity, it was shown [51] that repeated elicitation of the acoustic startle reflex led to sensitization, subsequent avoidance behavior and induced fear conditioning. The data indicated that repeated startling by anthropogenic noise sources might have severe effects on long-term behavior.

An Iranian paper has lately reported [52] sleep disturbance in wind turbine workers, 53 of whom fell into three groups: mechanics, security staff and officials. The results showed that there was a positive and significant relationship between age, workers' experience, equivalent sound level, and the severity of sleep disorder. When age was constant, sleep disorders increased by 26% for each 1 dB increase in equivalent sound level. In situations where the equivalent sound level was constant, an increase in sleep disorder of 17% occurred for each year of work experience. There was a difference in sound exposure between the different occupational groups: the effect of noise in mechanics was 3.4 times greater than in the security group and about 6.5 times greater than in the official group. Sleep disorder caused by wind turbine noise was almost twice as high in the security group in comparison to the official group. It was concluded that the noise generated by wind turbines has health implications for everyone exposed to it.

In a study reported [53] from Japan, 15 subjects were experimentally exposed

to various sound stimuli, including recorded aerodynamic noise and Infrasound, along with synthetic periodic sound, and were evaluated by electroencephalography. The induced rate of *alpha*1 rhythm decreased when the test subjects listened to all the sound stimuli and decreased further with reducing frequency. In particular, the induced rate of *alpha*1 rhythm, when the sound stimulus lay in the frequency band of 20 Hz, produced the lowest rate of all. It was concluded that the subjects cannot relax comfortably when exposed to Infrasound.

The European Metrology Research Programme (EMRP) has now established that everyone, at least all 16 of the healthy 18 - 25-year-old volunteers studied, can perceive Infrasound down to 8 Hz [54]. This was the lowest frequency investigated and it is likely that even lower frequencies can be perceived. 'Perception' was assessed using functional magnetic resonance imaging (fMRI) and a significant response was detected which was localized within the auditory cortex and which was present down to 8 Hz. The signal strength of the blood-oxygen-level dependent (BOLD) signal showed a minimum at 20 Hz, so a further investigation of BOLD-signal's dependence on the loudness was carried out. A decreasing dynamic range of hearing in this frequency range was noted, accompanied by the finding that even sound signals with sound pressure levels only slightly above the threshold will be registered as annoying.

Several details in the brain imaging results suggested that, at frequencies around about 20 Hz, the perception mechanism might change or is realized by a combination of different processes. One hypothesis is that a somatosensory excitation of the auditory cortex contributes at these frequencies [54]. Thus, the idea is floated that we are perceiving Infrasound directly through our body surface. This fits in with the concept of the vibration of body structures espoused by Persinger [6]. In the Cape Bridgewater study, in which turbines were intermittently turned on and off, the subject who could best predict whether or not the rotors were in motion or not was profoundly deaf [55].

The latest EMRP study conducted on 14 subjects has demonstrated [56], using fMRI, that Infrasound of 12 Hz administered at sound pressure levels just below the hearing threshold can induce changes in neural activity across several brain regions. Some of these regions are known to be involved in auditory processing, while others are recognized as playing key roles in emotional and autonomic control. Paradoxically, these effects were not observed when subjects were exposed to Infrasound of 12 Hz above the hearing threshold, because, apparently, the brain can adjust to it. These findings provide intriguing evidence that continuous exposure to subliminal Infrasound may be harmful to the human brain. Such physiological or even psychological effects could be mediated via a subconscious processing route. The transient up-regulation of these brain regions in response to Infrasound at this level may therefore reflect an initial stressor response, with symptoms becoming established through constant exposure.

The EMRP authors observe [56] that a large part of the Infrasound that we are exposed to in our daily environment is produced by continuous sources such as wind-turbines and traffic. They argue that it is these sources of constant and

subtle Infrasound, which may not attain a level exceeding the threshold of perception, which exert influences on the nervous system. Thus it seems that low levels of Infrasound really are capable of getting in 'under the radar'. It is this very level of Infrasound which authorities such as Leventhall state cannot harm you and which WHO dismisses as having no physiological or psychological effects [56].

In addition, wind turbines can, and do, cause accidents by collapsing, blade snap, ice throw, and even going on fire. They induce stress and psychological disorder from shadow flicker, which also has implications for certain types of epilepsy and autism. Even the current planning process, with its virtual absence of consultation, is stress inducing, as is the confrontation between landowners, who wish to profit from erecting turbines, and their neighbours, who dread the effects on their health. Finally, wind turbines considerably reduce the value of dwellings nearby and this has a negative long-term effect on their owners' and their families' health [57]. On top of this, increasing numbers of families will be driven into fuel poverty by spiralling electricity costs which are subsidizing wind energy.

2.4. Controlling Wind Farm Noise

Another aspect is that the instruments and methods used to assess the cut-points may be inappropriate or inaccurate. The United Kingdom's Batho Report of the Noise Review Working Party in 1990 identified [58] low frequency noise as having a serious effect on those exposed to it. It also commented that the use of the A-weighted scale to assess low frequency noise was not appropriate. The A-weighted scale was in fact designed to reflect the normal human auditory range for many common urban/suburban noise sources. The rationale for this derives from work published by Fletcher and Munson [59] in 1933 using pure tones and ear-occluding headsets (headphones) with the object of increasing the distance over which the human voice could be transmitted by telephone wire. The tests were therefore conducted in a setting intended to mimic the use of an ear-occluding headset, *i.e.*, a telephone. The use of occluded ears and pure tones is a totally artificial situation and not directly comparable to "free-field" hearing. Normal hearing occurs in "free field", without occluding the ear, and in the presence of many other background sounds.

When a noise emits more Infrasound and low frequency energy than usual, the use of A-weighted thresholds and measurements is not protective. If unweighted Infrasound measurements had been used to investigate Sick Building Syndrome, its generally accepted cause, Infrasound and low frequency rumble, could have been detected much earlier [60]. It has been known for a long time that fans turning inside buildings can make people sick [61] and there are questions remaining about the effects of even larger fans turning outside buildings [60], *i.e.* wind turbines.

The problem of Infrasound and low frequency noise was well-recognized in a Report by Casella Stanger, commissioned by DEFRA in 2001 [62] with the

statement that: "It should not be regarded as formal guidance from DEFRA", but what is unclear is just when this advice was added. The Report advises, "For people inside buildings with windows closed, this effect is exacerbated by the sound insulation properties of the building envelope. Again, mid and high frequencies are attenuated to a much greater extent than low frequencies." It continued: "As the A-weighting network attenuates low frequencies by a large amount, any measurements made of the noise should be with the instrumentation set to linear." It drew heavily upon the Batho Report of 1990 [58]. In fact, these problems had already been elucidated and the measurement issues addressed in a trio of papers by Kelley and his colleagues in the 1980s [63] [64] [65]. Kelley and his colleagues began investigating a single turbine at Boone, North Carolina, in late 1979 when around 12% of families within 3 km where impacted by noise emissions from a single wind turbine. The 237-ft high 2 MW turbine with four cylindrical legs was perched "atop Howard's Knob" and the passage of the rotors past the legs caused low frequency pressure pulsations to be propagated into the structures in which the complainants lived. The situation was aggravated further by a complex sound propagation process controlled by terrain and atmospheric focusing. The report runs to 232 pages and is certainly comprehensive [64].

The annoyance was described as an intermittent "thumping" sound accompanied by vibrations. A "feeling" or "presence" was described, felt rather than heard, accompanied by sensations of uneasiness and personal disturbance. The "sounds" were louder and more annoying inside the affected homes. Some rattling of loose objects occurred. In one or two instances, structural vibrations were great enough to cause dust to fall from high ceilings and create an additional nuisance. The noise was found to be more persistent and perhaps more severe at night. Moreover, it was noted as being worse in small rooms, usually bedrooms. The impulsiveness of the emitted low frequency acoustic radiation was identified as a major factor in determining not only the level of potential annoyance to residents within a structure, but perception as well. Various recommendations were made concerning noise reduction [65].

Kelley and his colleagues' research was promoted at conferences on wind turbine noise but seems to have been ignored or forgotten, so the problem continues to be seriously underestimated. When measured using a tool which can detect it, levels of Infrasound and low frequency noise are disturbingly high, with 'sound pressure levels' greater than previously thought possible [66]. It has also been demonstrated that infrasonic noise interferes with the micro-mechanics of the human inner ear [67].

In February 2003, the UK Department of Trade and Industry launched [68] 'Our Green Energy Future,' which committed the country to wind energy. Despite the existence of the Casella Stanger Report warning about Infrasound and low frequency noise and its caveats about how it should be assessed, the Government used another Report dated May 2003 which told a rather different story [5]. Although a lot more comprehensive than the Casella Stanger Report [62], it

was aligned with the ETSU-R-97 recommendations [69] (see below). This is all rather reminiscent of the allegedly "Dodgy Dossier" which the then Prime Minister, Tony Blair, used to launch the UK's involvement in the Iraq war the same year. It was published by the same Government Department which had published the Casella Stanger Report two years before. This looked remarkably like the Government commissioning the report which would facilitate its energy policy.

The Report by Leventhall [5], who has acted as a noise consultant to wind companies, actually states, "The effects of Infrasound or low frequency noise are of particular concern because of its pervasiveness due to numerous sources, efficient propagation, and reduced efficiency of many structures (dwellings, walls, and hearing protection) in attenuating low frequency noise compared with other noise," but it seems that this was the work of a co-writer. Despite this, the message conveyed is that modern wind turbines are not an important source of Infrasound and the use of A-weighting is entirely adequate. The report also states that "Infrasound exposure is ubiquitous in modern life." This may be so, but Persinger makes [6] the point that naturally occurring Infrasound, including that produced within our own bodies, is random, whereas wind turbine Infrasound is pulsatile; and it is this quality which causes health problems.

The message concerning the appropriateness of using A-weighting in assessing sound has recently been reasserted by Leventhall and three of his fellow acousticians [70]. This was in spite of the fact that three of them had previously recommended, in joint and separate statements and publications, that Infrasound should be viewed as a source of adverse effects.

2.5. Wind Farm Guidelines

In the UK, the construction of wind farms is predicated on ETSU-R-97 which was organized by the wind industry, ably assisted by acousticians and others associated with the industry, without a single Sleep Physician, in 1996-1997 [69]. The authors state in the executive summary: "This document describes a framework for the measurement of wind farm noise and gives indicative noise levels thought to offer a reasonable degree of protection to wind farm neighbors, without placing unreasonable restrictions on wind farm development or adding unduly to the costs and administrative burdens on wind farm developers or local authorities." Despite these lofty ideals, a recent review observed [71]: "Exposure to wind turbines does seem to increase the risk of annoyance and self-reported sleep disturbance in a dose-response relationship. There appears, though, to be a tolerable level of around L_{Aeq} of 35dB. " This is about 6 dB less than the permitted ETSU-R-97 night time level, implying a doubling of the setback (assuming a decay of noise level of 6 dB per doubling of distance). The ETSU-R-97 recommendations were based on the turbines of the mid 1990s which had a hub-height of 32 m, whereas today's turbines are several times taller with blades that are much longer and more flexible.

Applying the ETSU-R-97 methodology, which is still in force, setback dis-

tances for human habitation from modern 2.5 - 3 MW turbines are in the region of 500 - 600 m. There are good reasons for believing that these setbacks are woefully inadequate. A 2013 Marshall Day Acoustics 'Examination of the significance of noise in relation to onshore wind farms' [72], commissioned by the Sustainable Energy Authority of Ireland, reproduces a graph from the Møller and Pedersen paper of 2011 [73]. This shows how the noise emitted by a turbine increases with size. In fact, a doubling in turbine generating capacity from 1 MW to 2 MW may result in slightly more than a doubling of the overall A-weighted sound power level, that is, an increase of more than 3 dB. Also, for a range of turbines with the same power generating capacity, sound level output can vary by several decibels. Moreover, it was noted that while audible sound increased with increasing turbine size, the emission of low frequency sound was disproportionally greater. Shifting the acoustic energy into the lower frequencies renders A-weighted measurements and guidelines even less applicable. These data applied to turbines up to 3.6 MW, but are expected to apply to even larger ones. It was noted that the relationship is not necessarily statistically significant, which may well be the case, but it is almost certainly biologically significant.

In Ireland, the current setback, introduced in 2006, is a mere 500 m, although there have been repeated promises by government to increase it [74]. There are also concerns about the use of average noise levels as these smooth out the peaks. It is these sound pressure peaks which may be sensitizing people to noise, as has been shown in the case of seals [51]. Averaging only serves to conceal important characteristics which exert adverse effects on living things.

In 2008, the distinguished American acoustic engineers, George Kamperman and Richard James, posed [75] the question: "What are the technical options for reducing wind turbine noise emission at residences?" They observed that there were only two options: i) increase the distance between source and receiver; or ii) reduce the source sound power emission. They added that neither solution is compatible with the objective of the wind farm developer to maximize the wind power electrical generation within the land available. They also highlighted the fact that Vestas' employees are not allowed to go within 400 m of a turbine while it is in motion. Turbines can produce Infrasound even when they are not running when wind excites the tower and blades. Long-range measurements from two different wind farms over a distance of 80 km have shown that Infrasound below 6 Hz has a propagation loss approximating to 3 dB per doubling of distance [76].

Lastly, carpeting the Irish landscape with wind turbines has led to a proliferation in power lines which come with their own health risks. An association between living close to high voltage power lines and the development of childhood leukemia has been consistently observed [77]. Recent epidemiological studies are in agreement with earlier findings of an increased risk of childhood leukemia with estimated daily average exposures above 0.3 to 0.4 μT. Although no mechanisms have been identified and consequently causality cannot be ascribed [77], in view of its serious nature the association cannot simply be ignored.

2.6. What Studies Should be Mounted?

Although the associations between noise pollution, particularly from Infrasound and low frequency noise, and ill health can be argued against, and there are gaps in our knowledge, there is sufficient evidence to cause grave misgivings about its safety. Further research, supported by adequate funding, remains necessary. Good and caring Government should entail acting with greater caution when its policies could jeopardize the Health and Human Rights of its people.

So what studies need to be mounted? Hessler and his colleagues, as well as upholding [70] the adequacy of A-weighting, pose the question: "Do wind turbines make people sick? That is the issue."

This paper, written by four "scientists in the wind turbine acoustical field" who "do not doubt for a moment the sincerity and suffering of some residents close to wind farms and other low frequency sources, and this is the reason all four would like to conduct, contribute or participate in some studies that would shed some light on this issue." This all sounds very laudable, but the basic contention of their paper is that there is no adverse human health effect from low frequency noise and Infrasound, provided that A-weighting is used to measure them and current guidelines are adhered to. What, precisely, qualifies them to pronounce on health issues is obscure.

They continue: "It must also be said that it is human nature to exaggerate grievances and that some qualitative measure must be made available to compensate affected residences." It is hard to assimilate the logic of this sentence, but the first part is clearly intended as an antidote to the residents' "sincerity and suffering" described earlier in the paragraph. It should be pointed out that babies, young children, and animals that are unable to "exaggerate grievances" are also seriously impacted when exposed to low frequency noise and Infrasound, eg badgers [78], pigs [79], crabs [80] and, perhaps, even plants [81]. The phrase "exaggerate grievances" is also redolent of accusing sufferers of hysteria, which is all rather cynical. A similar fate befell Myalgic Encephalomyelitis sufferers when they had their condition derisively dismissed as "Yuppie Flu", until in 2011, when it was finally accepted as a true disease entity and International Consensus Criteria were developed [82].

Some of the studies the "scientists" propose [70] are not particularly scientifically robust: e.g., National Surveys, collecting cross-sectional data which may reveal associations, which, no matter how strong, cannot establish causation, are slow, inconclusive and favor the *status quo*; and Noise Source Reduction, *i.e.* trying to reduce noise emissions from turbines, which seems welcome but oddly similar to the tobacco industry's attempts to reduce tar in tobacco while ignoring the fact that tobacco smoke contains a cocktail of noxious elements [83], as wind turbine noise certainly also does. For example, in addition to Infrasound, Amplitude Modulation related to wake interference between turbines [84] can effectively double the noise produced. This is particularly likely to occur when turbines are crowded too close together, which also reduces their output [85].

Some other suggestions are better such as Perception Testing to investigate

whether receivers have the ability to detect a turbine's activity without actually seeing or hearing it. It seems that it is only a minority, albeit a significant one, which is impacted by it. Moreover, whichever pathway transmits Infrasound to the brain is immaterial as it is unquestionably registered there. As noted above, one person who is sensitive to feeling the pulsations has nerve deafness. Furthermore, published reports by acousticians who are sensitive to infrasonic pressure pulses should establish that people can feel them even when sound pressure levels are insufficient to achieve the threshold of audibility [86].

The Recommendation [70] concerning Simulation appears the most sensible, by duplicating and simulating low frequency noise and Infrasound with loudspeakers, and exposing volunteers to high and low levels, to establish threshold levels. This approach would be valid if the sound correctly reflects what is experienced by people exposed to wind turbine noise. Such is the nature of the pulsations that electronic systems employing loudspeakers cannot reproduce them accurately. This all begs the question as to why not carry out this study in the field and measure some hard endpoints?

As the authors point out: "Realistically, it is not even possible to answer the posed question to all parties' satisfaction with practical research. For examples, a direct link to adverse health effects from yesterday's tobacco and today's excess sugar can be denied forever, because any research that could actually prove a link to all parties would take longer than forever and would be totally impractical." Surely there is ample evidence that sugar consumption, as it is a rich source of calories, is associated with obesity? This, although arguably not a disease in itself, is a powerful marker for a range of diseases. In this sense obesity represents a strong "intermediate phenotype" lying on the physio-pathological pathway between health and disease. Similarly, in relation to tobacco, there are biomarkers which are elevated in people who smoke and which indicate an increased risk of lung and other associated cancers [83].

So, does Infrasound and low frequency noise emitted by wind turbines make people sick? The authors comment [70] that, "It is abundantly obvious that intense adverse response occurs at certain sites" but stop short of admitting that it does make people sick, despite their having investigated complaints reported to them by adversely affected citizens. The authors support wind energy: "Likewise, wind farm opponents must accept reasonable sound limits or buffer distance to the nearest turbine—not pie-in-the-sky limits to destroy the industry." This all depends on what is considered "reasonable."

It is abundantly clear that sound levels involve a similar, continuous increase in risk, in a similar way that the amount of tobacco smoked determines [81] the risk of lung cancer. That is why cut-points for the levels of sound permitted were established in an attempt to protect receivers. What we have learned about cut-points in the past, for example from the asbestos scandal, is that, from the outset, cut-points are invariably placed too high and constantly need to be reduced [30].

In the late 18th century, the great Scottish Anatomist, John Hunter, wrote to his protégé, Edward Jenner, asking him: "Why think? Why not do the experi-

ment?" [87]. He was exhorting Jenner to measure the core temperature of a hibernating hedgehog. We all have remnants of the genes for hibernation but we don't express them [88]. Similarly, in common with some animals, we possibly all have the genes for reacting to Infrasound, but only some of us express them.

It would be perfectly feasible to mount an experiment, a randomized cross-over trial, in which persons impacted by wind farm noise have their biomarker levels [25] [89] measured after standardized periods of exposure and non-exposure to wind turbine noise. In this way, each person would act as his or her own control. A well-devised trial could be of modest size, be cheap to conduct and deliver results relatively quickly. Assessment of the blood transcriptome [26] would increase the scope of such a trial, as would cortisol assessment [78]. This study could be augmented with the 'Simulation' study proposed by the authors to identify critical frequencies and sound levels if a test chamber and audio system can be devised which accurately reproduces the pulsations experienced in people's homes. Besides, the comparison of means makes for a more powerful statistical analysis. This sort of study will quickly indicate whether exposure to wind turbine noise is safe or not. It has a huge advantage over prospective studies which will take years to accumulate hard disease endpoints, as was the case with tobacco. For many people exposed to industrial wind turbines the question as to whether they can feel or otherwise sense them has already been answered. Could the reluctance of the wind industry to mount the appropriate studies be due to the worldwide spate of complaints from those exposed to wind turbine noise?

The Salford Report, again written [32] by a group of acousticians without any input from sleep experts, concluded that there is "... some evidence for sleep disturbance which has found fairly wide, though not universal, acceptance." The increasing weight of evidence of sleep deprivation's association with several chronic diseases is totally ignored. The authors of the Report are at pains to deny any "direct" health effects. In terms of prevention, any differentiation between 'direct' and 'indirect' is irrelevant: in 271 BC, the Roman consul Manius Curius Dentatus ordered the construction of a canal (*the Curiano Trench*) to divert the stagnant waters surrounding the River Velino in Umbria over the natural cliff at Marmore, to produce Cascata delle Marmore [90]. Romans had an aversion to drinking stagnant water and went to great lengths to "drain the swamp" because they associated it with illness. In this case the stagnant water was only "indirectly causal" but was vital to the propagation of Malaria, and hence draining the swamp abolished Malaria locally.

Governments pursuing renewable energy targets must adhere to the *Precautionary Principle* (see below). They have a duty to commission appropriate studies to ensure that the health of their rural citizens is adequately protected. It might be assumed that the wind industry would have carried out these studies as part of its "due diligence", but, to date, no such studies have been forthcoming.

3. The Public Health Perspective

3.1. Public Health and Utilitarianism

Public Health developed in different ways in different countries. In Europe, Johann Peter Frank's *System einer vollstädigen medinischen Polizey* was particularly influential [91]. Frank's epic work was published in six volumes between 1779 and 1817 and promoted the concept of "Medical Police". The word 'Police' here connotes public administration. It was taken up by Andrew Duncan (Senior) in the Edinburgh University Medical School, who published a "Memorial" in 1798 presenting an outline of what he saw as a comprehensive course of instruction in Medical Police [92]. The concept spread to Ireland, where Henry Maunsell was appointed as Professor of Political Medicine at the Royal College of Surgeons of Ireland in 1841 [93].

The concept was also adopted in England, where Edwin Chadwick wrote upon Preventive Police in 1829 [94]. Chadwick was a lawyer and "…'the bureaucratic radical'… disciple of the archutilitarian [sic] Jeremy Bentham," who in 1842 was to publish his famous *Report on the Sanitary Conditions of the Labouring Population of Great Britain*, which he wrote in his position as Secretary to The Poor Law Commissioners. As a young man, Chadwick was Bentham's assistant and he afterwards applied Bentham's Utilitarian principles to Public Health [95]. Chadwick's *Report* paved the way for the establishment of the General Board of Health in 1848, under the great Public Health Act [96]. Chadwick's work heading the Board strongly influenced the thinking of doctors such as John Simon, and this marks the birth of Public Health in England [96] and the Medical Officers of Health. Thus, in Britain, modern Public Health grew out of the Utilitarian philosophy, developed by Jeremy Bentham, which enshrined the ethos that a morally good action is one that helps the greatest number of people.

However, it now seems that economic growth, particularly during a recession, is such an important goal that other aspects, such as health, are seen as being of secondary importance. It is essential that Public Health should increase its vigilance; to do any less would be to betray its proud past.

3.2. Collateral Damage

In the United Kingdom in1853, a Vaccination Act was passed: it was a *compulsory* act which decreed that all parents had to have their infants vaccinated against Smallpox within three months of birth. It supplanted the *permissive* Vaccination Act of 1840, which simply hadn't worked. Although it was known that a small proportion of children would succumb to the effect of the vaccination, this was trifling in comparison to the number of deaths from Smallpox which would be prevented [97]. In effect, Public Health had accepted the principle of *Collateral Damage*, provided that the overall benefit was large and the damage was small. Eventually, by the 1970s, vaccination was phased out because as the eradication of Smallpox approached, vaccinia was claiming more lives than Smallpox was [98].

3.3. The Precautionary Principle

The problem is just how much *Collateral Damage* is acceptable? When the BSE epidemic emerged in the late 1980s, the Government insisted that, providing simple measures were applied, beef was perfectly safe. The Minister of Agriculture went public and was photographed administering a hamburger to Cordelia, his four-year-old daughter [99]. Instead of applying the *Precautionary Principle* (enabling rapid response in the face of a possible danger to human, animal or plant health) [100], which should have triggered primate feeding experiments, the Government decided to tough it out, apparently for the health of the Farming Industry rather than for the health of its citizens. It compromised by having neural tissue separated from meat, seemingly oblivious of the fact that nerves innervate muscle. In effect, the experiment was being carried out on an unsuspecting populace.

In 1996, the first vCJD cases were identified and epidemiologists predicted thousands of deaths. Public Health was remarkably quiet on the issue but, to date, the disease has only resulted in 177 deaths. The reason that it has not been higher lies in the fact that there is a very specific genetic element as to who will develop the disease. There were no long-term monitoring measures put in place, but *ad hoc* studies indicate that the number of people infected with abnormal prion protein may be in the region of 30,000 [101]. Although representing only a small proportion of the total population, it still lies uneasily with Utilitarian principles in that the level of possible *Collateral Damage* was unacceptably large.

A similar population experiment seems to be underway in terms of environmental noise pollution. Governments, faced with economic recession, have been keen to increase economic activity and meet Green targets. As a result, environmental noise has increased. Public Health must maintain its position as champion of the health of the public and not just slavishly back up government policy. How can it be that environmental noise pollution continues to escalate despite the very real adverse effects it exerts on human health? A recent report from the Royal Society of Public Health has placed stress [102] on the importance of sleep to health. This is all very well, but nowhere in the 30-page document is there a mention of the role of noise in disrupting sleep, in fact the word "noise" is completely omitted. Perhaps the Royal Society was anxious not to open the noise can of worms? In her 'Notes on Nursing' in 1859 [103], Florence Nightingale was not so squeamish, because when she extolled the importance of sleep to health, she was also attuned to the deleterious effects of noise: "Unnecessary noise…is the most cruel absence of care which can be inflicted either on sick or well."

As sleep deprivation is the most important health-damaging effect of environmental noise pollution, Public Health should be treating the matter very seriously. Indeed, the United Nations Committee Against Torture (UN CAT) has explicitly identified "sleep deprivation for prolonged periods" [104] as a method of torture. In 1978, in a case taken to Europe by the Irish Government, the British Government was found guilty of applying five techniques, including subjection to noise and deprivation of sleep [57]. These were used in Ulster to 'en-

courage' admissions and to elicit information from prisoners and detainees. They amounted to humiliating and degrading treatment, *i.e.* torture. Although the judgment was afterwards overturned on appeal, and downgraded to 'inhuman or degrading treatment', the action is still alive. The case being taken by 'The Hooded Men' is being backed by the Irish Government [105]. This same Government, by its failure to revise the turbine setback guidelines, is imposing noise and sleep deprivation on its rural citizens.

3.4. Public Health's Responsibilities

When Public Health doctors are asked about possible health effects, they tend to dismiss the literature as either non-peer-reviewed, or if it is a review, non-systematic. If they want to read a comprehensive, thorough and systematic review, they should look no further than that by Punch and James [106]. The Public Health Agencies in the UK are now relying on a document published in April 2013 which is also not peer-reviewed [32]. As already mentioned, was written by a group of acousticians at the University of Salford, which begs the question as to why such a group was selected to pronounce on health issues. Since acousticians derive a significant proportion of their income from the wind industry, their scientific objectivity might be open to question. Similarly, if a profession which worked closely with the tobacco industry was asked to report on health, questions would be asked.

Recently, a Vestas PowerPoint presentation from 2004 has surfaced [107] demonstrating that Vestas knew over a decade ago that safer buffers were required to protect neighbors from wind turbine noise. They knew their pre- construction noise models were inaccurate and that "...we know that noise from wind turbines sometimes annoys people even if the noise is below noise limits." Similarly, we are repeatedly told that modern turbines are quieter and produce less Infrasound and low frequency noise, which in reality is the reverse of the case. Denmark has been in the vanguard of wind energy development and there is a Danish initiative entitled "WIND2050" [108]. This appears to seek to promote the interests of the wind industry, particularly through encouraging "Community Ownership" of wind farms. To enable this, the project is "mapping criticism", *i.e.* assembling maps to show where rural citizens have raised any objection to wind farm development. It seems analogous to tobacco companies keeping smoking cessation clinics under surveillance.

There has been a tendency for Public Health to toe the official line that wind farms are entirely safe. This is the message promulgated by the wind industry so Public Health should be evaluating the evidence more critically. If Public Health doctors actually visited the families who have been forced to abandon their homes they might demand to see the necessary studies conducted. They would learn that some of the worst affected are small children who are very often put in the smaller bedrooms which are worst impacted by noise [64]. There is also the intriguing possibility that if Infrasound is conducted through the skin [54], young children will receive a larger dose because their surface area is greater in

relation to their volume in comparison to adults. This is why small children lose heat faster than adults.

To her credit, in 2014, one Irish Public Health doctor, the Deputy Chief Medical Officer, actually stated that while turbines do not represent a threat to Public Health, "there is a consistent cluster of symptoms related to living in close proximity to wind turbines which occurs in a number of people in the vicinity of industrial wind turbines" and that "These people must be treated appropriately and sensitively as these symptoms can be very debilitating" [109]. The Irish Wind Energy Association promptly rounded on her with the accusation of her "having focused on out-of-date information," but she stood her ground admirably.

In view of the foregoing considerations, and because Public Health's apparent official view is that there are no important health effects caused by exposure to wind turbine noise, a reappraisal of the evidence is overdue. Public Health doctors should be conducting focused epidemiological studies, but this is something that they haven't displayed much aptitude for of late. Apart from anything else, Public Health should be rigorously applying the *Precautionary Principle* or *Primum non nocere* (First, do no harm) ideal, putting monitoring and evaluation in place and then undertaking the appropriate studies. A recent review of peer-reviewed studies published between 2000 and 2015 concluded [110] that the estimated pool prevalence of high subjective annoyance was around 10%. This figure is very close to that found by Kelley [64] and his colleagues cited above, although the true figure may well be higher. The authors observed that epidemiological research on low frequency noise is scarce and suffers from methodological shortcomings. They added that low frequency noise in the everyday environment is an issue which requires more research attention, particularly for people living in the vicinity of relevant sources.

Environmental noise pollution, particularly when it deprives people of sleep, is especially related to the development of CVD, as a recent paper concluded that: "... the public health impact of sufficient sleep duration, in addition to the traditional healthy lifestyle factors, could be substantial" [36]. Public Health must take its responsibilities seriously to protect the Health and Human Rights of all citizens. Despite a desire to meet various Renewable Energy targets, Government must ensure that the appropriate studies are undertaken in order to protect the sizeable minority of the exposed population which suffers adverse effects. In fact, Jeremy Bentham shrewdly anticipated the necessity for Government support for research in both theory and practice [111]. In the 19th century, Public Health acted to protect the health of town dwellers, thrown together by the Industrial Revolution. People had moved from the country into towns where they were exposed to industrial pollution. We are now witnessing the reverse process, a second Industrial Revolution, in which large industrial machines are being imposed on rural dwellers, and Public Health must act to see that sufficient safeguards are put in place so that rural citizens' health is fully pro-

tected.

As Bradford Hill observed [112] over half a century ago: "The lessons of the past in general health and safety practices are easy to read. They are characterised by empirical decisions, by eternally persistent reappraisal of public health standards against available knowledge of causation, by consistently giving the public the benefit of the doubt, and by ever striving for improved environmental quality with the accompanying reduction in disease morbidity and mortality". Quite so, it is high time that Public Health gave the public the benefit of the doubt.

4. Conclusion

So has Public Health become too utilitarian? All the available evidence indicates that an important minority of local inhabitants is severely impacted by noise emitted by wind farms sited too close to their homes. This degree of *Collateral Damage* is too large to accept in terms of Utilitarianism. Public Health must exercise the *Precautionary Principle* and retain as much independence from government as possible in assessing the health effects of national policies. The Health and Human Rights of rural-dwelling citizens are every bit as important as those of the rest of society. In fact, in terms of wind energy, the overall benefit is fairly modest [113] [114] and the adverse effect on people's health is far from small. It is essential that separation distances between human habitation and wind turbines are increased. There is an international consensus emerging for a separation distance of 2 km; indeed some countries are opting for 3 km and more. Furthermore, the appropriate, focused studies should be undertaken as soon as possible.

References

[1] Münzel, T., Gori, T., Babisch, W. and Basner, M. (2014) Cardiovascular Effects of Environmental Noise Exposure. *European Heart Journal*, **35**, 829-836. https://doi.org/10.1093/eurheartj/ehu030

[2] Meyer, A.F. (1971) EPA's Noise Abatement Program. United States Environmental Protection Agency, Washington DC.

[3] Basner, M., Babisch, W., Davis, A., *et al.* (2014) Auditory and Non-Auditory Effects of Noise and Health. *The Lancet*, **383**, 1325-1332.

[4] Mead, M.N. (2008) Benefits of Sunlight: A Bright Spot for Human Health. *Environmental Health Perspectives*, **116**, A160-A167.

[5] Leventhall, G. (2003) A Review of Published Research on Low Frequency Noise and Its Effects. Report for DEFRA.

[6] Persinger, M.A. (2014) Infrasound, Human Health, and Adaptation: An Integrative Overview of Recondite Hazards in a Complex Environment. *Natural Hazards*, **70**, 501-525.

[7] Salt, A. and Lichtenhan, J.T. (2014) How Does Wind Turbine Noise Affect People? *Acoustics Today*, Winter, 20-28.

[8] Hubbard, H.H. (1982) Noise Induced House Vibrations and Human Perception. *Noise Control Engineering Journal*, **19**, 49-55. https://doi.org/10.3397/1.2827592

[9] Kelley, M.C. and Garstang, M. (2013) On the Possible Detection of Lightning Storms by Elephants. *Animals*, **3**, 349-355. https://doi.org/10.3390/ani3020349

[10] Ledley, F.D. (1982) Evolution and the Human Tail: A Case Report. *The New England Journal of Medicine*, **306**, 1212-1215. https://doi.org/10.1056/NEJM198205203062006

[11] Nimura, Y. and Nei, M. (2003) Evolution of Olfactory Receptor Genes in the Human Genome. *Proceedings of the National Academy of Sciences of the United States of America*, **100**, 12235-12240. https://doi.org/10.1073/pnas.1635157100

[12] World Health Organisation (2009) Night Noise Guidelines for Europe. WHO Regional Office for Europe, Copenhagen.

[13] Boselli, M., Parrino, L., Smerieri, A. and Terzano, M.G. (1998) Effect of Age on EEG Arousals in Normal Sleep. *Sleep*, **21**, 351-357.

[14] World Health Organisation (2011) Burden of Disease from Environmental Noise: Quantification of Healthy Life Years Lost in Europe. WHO Regional Office for Europe, Copenhagen.

[15] Fields, J.M., De Jong, R.G., Gjestland, T., *et al.* (2001) Standardized General-Purpose Reaction Noise Questions for Community Noise Surveys: Research and a Recommendation. *Journal of Sound and Vibration*, **242**, 641-679.

[16] Ohrstrom, E., Skanberg, A., Svensson, H. and Gidlof-Gunnarsson, A. (2006) Effects of Road Traffic Noise and the Benefit of Access to Quietness. *Journal of Sound and Vibration*, **295**, 40-59.

[17] Hume, K.I., Brink, M. and Basner, M. (2012) Effects of Environmental Noise on Sleep. *Noise & Health*, **14**, 297-302.

[18] He, Q., Zhang, P., Li, G., Dai, H. and Shi, J. (2017) The Association between Insomnia Symptoms and Risk of Cardio-Cerebral Vascular Events: A Meta-Analysis of Prospective Cohort Studies. *European Journal of Preventive Cardiology*. https://doi.org/10.1177/2047487317702043

[19] Chung, S.A., Wolf, T.K. and Shapiro, C.M. (2009) Sleep and Health Consequences of Shift Work in Women. *Journal of Women's Health*, **18**, 965-977. https://doi.org/10.1089/jwh.2007.0742

[20] Carter, P.J., Taylor, B.J., Williams, S.M. and Taylor, R.W. (2011) Longitudinal Analysis of Sleep in Relation to BMI and Body Fat in Children: The FLAME Study. *BMJ*, **342**, d2712. https://doi.org/10.1136/bmj.d2712

[21] Hanlon, E.C., Tasal, E., Leproult, R., *et al.* ((2016) Sleep Restriction Enhances the Daily Rhythm of Circulating Levels of Endocannabinoid 2-Arachidonoglycerol. *Sleep*, **39**, 653-664. https://doi.org/10.5665/sleep.5546

[22] Xie, L., Kang, H., Xu, Q., *et al.* (2013) Sleep Drives Metabolite Clearance from the Adult Brain. *Science*, **342**, 373-377. https://doi.org/10.1126/science.1241224

[23] Yang, G., Lai, C.S.W., Cichon, J., Ma, L., Li, W. and Gan, W.-B. (2014) Sleep Promotes Branch-Specific Formation of Dendritic Spines after Learning. *Science*, **344**, 1173-1178. https://doi.org/10.1126/science.1249098

[24] Sexton, E.S., Storsve, A.B., Walhovd, K.B., Johansen-berg, H. and Fjell, A.M. (2014) Poor Sleep Quality Is Associated with Increased Cortical Atrophy in Community-Dwelling Adults. *Neurology*, **83**, 967-973. https://doi.org/10.1212/WNL.0000000000000774

[25] Irwin, M.R., Olmstead, M.R. and Carroll, J.E. (2016) Sleep Disturbance, Sleep Duration and Inflammation: A Systematic Review and Meta-Analysis of Cohort Studies and Experimental Sleep Deprivation. *Biological Psychiatry*, **80**, 40-52. https://doi.org/10.1016/j.biopsych.2015.05.014

[26] Möller-Levet, C.S., Archer, S.N., Bucca, G., *et al.* (2013) Effects of Insufficient Sleep on Circadian Rhythmicity and Expression Amplitude of the Human Blood Transcriptome. *Proceedings of the National Academy of Sciences of the United States of America*, **110**, E1132-E1141.

[27] Archer, N.A., Laing, E.E., Möller-Levet, C.S., *et al.* (2014) Mistimed Sleep Disrupts Circadian Regulation of the Human Transcriptome. *Proceedings of the National Academy of Sciences of the United States of America*, **111**, E682-E691. https://doi.org/10.1073/pnas.1316335111

[28] Hansell, L.H., Blangiardo, M., Floud, F., *et al.* (2013) Aircraft Noise and Cardiovascular Disease near Heathrow Airport in London: Small Area Study. *BMJ*, **347**, 15432.

[29] Greiser, E. and Glaeske, G. (2013) Social and Economic Consequences of Night-Time Aircraft Noise in the Vicinity of Frankfurt/Main Airport. *Gesundheitswesen*, **75**, 127-133.

[30] Bartrip, P.W. (2004) History of Asbestos Related Disease. *Postgraduate Medical Journal*, **80**, 72-76.

[31] Hanning, C.D. and Evans, A. (2012) Wind Turbine Noise. *BMJ*, **344**, e1527. https://doi.org/10.1136/bmj.e1527

[32] von Hünerbein, S., Moorhouse, A., Fiumicelli, D. and Baguley, D. (2013) Report on Health Impacts of Wind Turbines. Prepared for Scottish Government by Acoustics Research Centre, University of Salford.

[33] Smith, M.G., Ögren, M., Thorsson, P., Pedersen, E. and Waye, K.P. (2016) Physiological Effects of Wind Turbine Noise on Sleep. *Proceedings of the 22nd International Congress on Acoustics*, Buenos Aires, 5-9 September 2016, 440.

[34] Onakpoya, I.J., O'Sullivan, J., Thompson, M.J. and Heneghan, C.J. (2015) The Effect of Wind Turbine Noise on Sleep and Quality of Life: A Systematic Review and Meta-Analysis of Observational Studies. *Environment International*, **82**, 1-9.

[35] Laugsand, L.E., Strand, L.B., Platou, C., Vatten, L.J. and Janszky, I. (2013) Insomnia and the Risk of Incident Heart Failure: A Population Study. *European Heart Journal*, **35**, 1382-1393. https://doi.org/10.1093/eurheartj/eht019

[36] Hoevenaar-Blom, M.P., Spijkerman, A.M.W., Kromhout, D. and Verschuren, W.M.M. (2013) Sufficient Sleep Duration Contributes to Lower Cardiovascular Disease Risk in Addition to Four Traditional Lifestyle Factors: The MORGEN Study. *European Journal of Preventive Cardiology*, **21**, 1367-1375. https://doi.org/10.1177/2047487313493057

[37] Hoevenaar-Blom, M.P., Annemieke, M.W., Spijkerman, A.M.W., Kromhout, D., van den Berg, J.F. and Verschuren, W.M.M. (2011) Sleep Duration and Sleep Quality in Relation to 12-Year Cardiovascular Disease Incidence: The MORGEN Study. *Sleep*, **34**, 1487-1492. https://doi.org/10.5665/sleep.1382

[38] Heidt, T., Sager, H.B., Courties, G., *et al.* (2014) Chronic Variable Stress Activates Hematopoietic Stem Cells. *Nature Medicine*, **20**, 754-758.

[39] Pierpont, N. (2009) Wind Turbine Syndrome: A Report on A Natural Experiment. K Selected Publications, Santa Fe, New Mexico.

[40] Sivertsen, B., Lalluka, T., Salo, P., *et al.* (2014) Insomnia as a Risk Factor for Ill Health: Results from the Large Population-Based Prospective HUNT Study in Norway. *Journal of Sleep Research*, **23**, 124-132. https://doi.org/10.1111/jsr.12102

[41] Salt, A.N. and Lichtenhan, J.T. (2011) Responses of the Inner Ear to Infrasound. *IVth International Meeting on Wind Turbine Noise*, Rome, Italy.

[42] Schomer, P.D., Edreich, J., Boyle, J. and Pamidighantam, P. (2011) A Proposed

Theory to Explain Some Adverse Physiological Effects of the Infrasonic Emissions at Some Wind Farm Sites. *5th International Conference on Wind Turbine Noise*, Denver, 28-30 August 2013.

[43] Ananthaswamy, A. (2013) Like Clockwork: The Cogs and Wheels That Drive Our Thoughts. *New Scientist*, **219**, 32-35.

[44] Danielsson, A. and Landström, U. (1985) Blood Pressure Changes in Man during Infrasonic Exposure. *Acta Medica Scandinavica*, **217**, 531-535. https://doi.org/10.1111/j.0954-6820.1985.tb03258.x

[45] Nussbaum, D.S. and Reinis, S. (1985) Some Individual Differences in Human Response to Infrasound. University of Toronto Institute for Aerospace Report No. 282, CN ISSN 0082-5225.

[46] International Standards Organisation (1996) Mechanical Vibration and Shock—Disturbance to Human Activity and Performance—Classification. 9996, Geneva.

[47] Lawther, A. and Griffin, M.J. (1987) Prediction of the Incidence of Motion Sickness from the Magnitude, Frequency, and Duration of Vertical Oscillation. *The Journal of the Acoustical Society of America*, **82**, 957. https://doi.org/10.1121/1.395295

[48] Castelo Branco, N.A.A., Alves-Pereira, M., Pimenta, A.M. and Ferreira, J.R. (2015) Low Frequency Noise-Induced Pathology: Contributions Provided by the Portuguese Wind Turbine Case. *EuroNoise*, Maastricht, 31 May-3 June 2015, 1-5.

[49] Mulholland, K.A. (1985) Noise Control. In: Tempest, W., Ed., *The Noise Handbook*, Academic Press, London, 281-301.

[50] Swinburn, T.K., Hammer, M.S., Richard, J.D. and Neitze, L.L. (2015) Valuing Quiet: An Economic Assessment of U.S. Environmental Noise as a Cardiovascular Health Hazard. *American Journal of Preventive Medicine*, **49**, 345-353. https://doi.org/10.1016/j.amepre.2015.02.016

[51] Götz, T. and Janik, V.M. (2011) Repeated Elicitation of the Acoustic Startle Reflex Leads to Sensitisation in Subsequent Avoidance Behaviour and Induces fear Conditioning. *BMC Neuroscience*, **12**, 30. http://www.biomedcentral.com/1471-2202/12/30 https://doi.org/10.1186/1471-2202-12-30

[52] Abbassi, M., Zakerian, S.A. and Yousefzadeh, A. (2015) Effect of Wind Turbine Noise on Workers' Sleep Disorder: A Case Study of Manjil Wind Farm in Northern Iran. *Fluctuation and Noise Letters*, **14**, Article ID: 1550020.

[53] Inagaki, T., Li, Y. and Nishi, Y. (2015) Analysis of Aerodynamic Sound Noise Generated by a Large-Scaled Wind Turbine and Its Physiological Evaluation. *International Journal of Environmental Science and Technology*, **12**, 1933-1944. https://doi.org/10.1007/s13762-014-0581-4

[54] Bauer, M., Sander-Thömmes, T., Ihlenfeld, A., Kühn, S., Kühler, R. and Koch, C. (2015) Investigation of Perception at Infrasound Frequencies by Functional Magnetic Resonance Imaging (fMRI) and Magnetoencephalography (MEG). *The 22nd International Congress on Sound and Vibration*, Florence, 12-16 July 2015, 1-6.

[55] Cooper, S. (2015) Personal Communication. Batho, W.J.S., Chair (1990) Noise Review Working Party Report. HMSO, London, 27.

[56] Weichenberger, M., Bauer, M., Kühler, R., *et al.* (2017) Altered Cortical and Subcortical Connectivity due to Infrasound Administered near the Hearing Threshold—Evidence from fMRI. *PLoS ONE*, **12**, e0174420. https://doi.org/10.1371/journal.pone.0174420

[57] Frey, B.J. and Hadden, P.J. (2012) Wind Turbines and Proximity to Homes: The Impact of Wind Turbine Noise on Health: A Review of the Literature & Discussion

of the Issues.
http://www.windturbinesyndrome.com/wp-content/uploads/2012/03/Frey_Hadden_WT_noise_health_01Jan2012.pdf

[58] Noise Review Working Party Report (1990) (Batho, W.J.S., Chair). HMSO, London, 27.

[59] Fletcher, H. and Munson, W.A. (1933) Loudness, Its Definition, Measurement and Calculation. *The Journal of the Acoustical Society of America*, **5**, 82-108. https://doi.org/10.1121/1.1915637

[60] James, R.R. (2012) Wind Turbine Infra and Low-Frequency Sound: Warning Signs That Were Not Heard. *Bulletin of Science, Technology & Society*, **32**, 108-127. https://doi.org/10.1177/0270467611421845

[61] Brűel, P.V. and Oleson, H.P. (1973) Infrasonic Measurements. *Inter-Noise*, 73, G23z3, Copenhagen, 22-24 August 1973.

[62] Casella Stanger (2001) Report on Low Frequency Noise Technical Research Support for DEFRA Noise Programme. On behalf of DEFRA, Department of the Environment, Northern Ireland, Scottish Executive, National Assembly for Wales.

[63] Kelley, N.D., Hemphill, R.R. and Mckenna, H.E. (1982) A Methodology for Assessment of Wind Turbine Noise Generation. *Transactions on ASME*, **104**, 112-120.

[64] Kelley, N.D., McKenna, H.E., Hemphill, R.R., Etter, C.I., Garrelts, R.I. and Linn, N.C. (1985) Acoustic Noise Associated with the MOD-1 Wind Turbine: Its Source, Impact, and Control. Solar Energy Research Institute, A Division of Midwest Research Institute, Golden, Colorado, USA.

[65] Kelley, N.D. (1987) A Proposed Metric for Assessing the Potential of Community Annoyance from Wind Turbine Low-Frequency Noise Emissions. *Presented at the Windpower'87 Conference and Exposition*, San Francisco, 5-8 October 1987. Solar Energy Research Institute, A Division of Midwest Research Institute, Colorado, USA.

[66] Bray, W. and James, R. (2011) Dynamic Measurements of Wind Turbine Acoustic Signals, Employing Sound Quality Engineering Methods Considering the Time and Frequency Sensitivities of Human Perception. *Proceedings of Noise-Con*, Portland, Oregon, 25-27 July 2011.

[67] Kugler, K., Wiegrebe, L., Grothe, B., *et al.* (2014) Low-Frequency Sound Affects Active Micromechanics in the Human Inner Ear. *Royal Society Open Science*, **1**, Article ID: 140166. https://doi.org/10.1098/rsos.140166

[68] Department of Trade and Industry (2003) Our Energy Future—Creating a Low Carbon Economy. HMSO, London.

[69] The Working Group on Noise from Wind Farms (1996) The Assessment and Rating of Noise from Windfarms. ETSU-R-97 Final Report, Department of Trade and Industry.

[70] Hessler, G., Leventhall, L.G., Schomer, P. and Walker, B. (2017) Health Effects from Wind Turbine Low Frequency Noise & Infrasound: Do Wind Turbines Make People Sick? That Is the Issue. Sound & Vibration, 34-44.

[71] Schmidt, J.H. and Klokker, M. (2014) Health Effects Related to Wind Turbine Noise Exposure: A Systematic Review. *PLoS ONE*, **9**, e114183. https://doi.org/10.1371/journal.pone.0114183

[72] Marshall Day Acoustics (2013) Examination of the Significance of Noise in Relation to Onshore Wind Farms. Commissioned by Sustainable Energy Authority of Ireland (SEAI), 29 November, 29.

[73] Møller, H. and Pedersen, C.S. (2011) Low-Frequency Noise from Large Wind Tur-

bines. *The Journal of the Acoustical Society of America*, **129**, 3727-3744. https://doi.org/10.1121/1.3543957

[74] Environment, Community and Local Government (2013) Proposed Revisions to Wind Energy Guidelines 2006: Targeted Review in Relation to Noise, Proximity and Shadow Flicker. 11 December 2013.

[75] Kamperman, G.W. and James, R. (2008) The "How To" Guide to Siting Wind Turbines to Prevent Health Risks from Sound. http://www.windturbinesyndrome.com/wp-content/uploads/2008/10/kamperman-james-8-26-08-report-43-pp.pdf

[76] Huson, L. (2015) Stationary Wind Turbine Infrasound Emissions and Propagation Loss Measurements (Paper I). *6th International Conference on Wind Turbine Noise*, Glasgow, 20-23 April 2015.

[77] Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR). Potential Health Effects of Exposure to Electromagnetic Fields (2015) European Commission, Brussels, Belgium. http://ec.europa.eu/health/scientific_committees/emerging/docs/scenihr_o_041.pdf

[78] Agnew, R.C.N., Smith, V.J. and Fowhes, R.C. (2016) Wind Turbines Cause Chronic Stress in Badgers (*Meles meles*) in Bitain. *Journal of Wildlife Diseases*, **52**, 459-467.

[79] Karwowska, M., Mikolajczak, J., Dolatowski, Z.J. and Borowski, S. (2015) The Effect of Varying Distances from the Wind Turbine on Meat Quality of Growing-Finishing Pigs. *Annals of Animal Science*, **15**, 1043-1054. https://doi.org/10.1515/aoas-2015-0051

[80] Pine, M.K., Jeffs, A.G. and Radford, C.A. (2012) Turbine Sound May Influence the Metamorphosis Behaviour of Estuarine Crab Megalopae. *PLoS ONE*, 7, e51790. https://doi.org/10.1371/journal.pone.0051790

[81] Hassanien, R.H.E., Hou, T., Li, Y. and Li, B. (2013) Advances in Effects of Sound Waves in Plants. *Journal of Integrative Agriculture*, **13**, 335-348.

[82] Carruthers, B.M., van de Sande, M.I., De Meirleir, K.L., *et al.* (2011) Myalgic Encephalomyelitis: International Consensus Criteria. *Journal of Internal Medicine*, **270**, 327-338. https://doi.org/10.1111/j.1365-2796.2011.02428.x

[83] Surgeon General (2010) How Tobacco Smoke Causes Disease: The Biology and Behavioral Basis for Smoking-Attributable Disease: A Report of the Surgeon General (3. Chemistry and Toxicology of Cigarette Smoke and Biomarkers of Exposure and Harm). Centers for Disease Control and Prevention (US), National Center for Chronic Disease Prevention and Health Promotion (US), Office on Smoking and Health (US), Atlanta (GA).

[84] Department of Energy and Climate Change (2016) Wind Turbine AM Review: Phase 2 Report. WSP/Parsons Brinckerhoff, Bristol.

[85] Miller, L.M., Brunsell, N.A., Mechem, D.B., *et al.* (2016) Two Methods for Estimating Limits to Large-Scale Wind Power Generation. *Proceedings of the National Academy of Sciences of the United States of America*, **112**, 11169-11174. https://doi.org/10.1073/pnas.1408251112

[86] Swinbanks, M.A. (2015) Direct Experience of Low Frequency Noise and Infrasound within a Windfarm Community. *6th International Meeting on Wind Turbine Noise*, Glasgow, 20-23 April 2015.

[87] Underwood, E.A. (1949) Edward Jenner: The Man and His Work. *BMJ*, 1, 881-884.

[88] Seldin, M.M., Byerly, M.S., Petersen, P.S., *et al.* (2014) Seasonal Oscillation of Liver-Derived Hibernation Protein Complex in the Central Nervous System of Non-Hibernating Mammals. *Journal of Experimental Biology*, **217**, 2667-2679.

[89] Dalgard, C., Eidelman, O., Jozwik, C., *et al.* (2017) The MCP-4/MCP-1 Ratio in Plasma Is a Candidate Circadian Biomarker for Chronic Post-Traumatic Stress Disorder. *Translational Psychiatry*, **7**, e0125. https://doi.org/10.1038/tp.2016.285

[90] Mapei, C. (MDCCCLVI) Italy, Classical, Historical and Picturesque. Blackie, Glasgow and London, 59-60.

[91] Rosen, G. (1953) Cameralism and the Concept of Medical Police. *Bulletin of the History of Medicine*, **27**, 21-42.

[92] Crew, F.A.E. (1949) Social Medicine as an Academic Discipline. In Massey, A., Ed., *Modern Trends in Public Health*, Butterworth, London, 46-79.

[93] Blaney, R. (1984) Henry Maunsell (1806-1879): An Early Community Physician. *Irish Journal of Medical Science*, **153**, 42-43. https://doi.org/10.1007/bf02940522

[94] Chadwick, E. (1829) Preventive Police. London Review I, 252-308.

[95] Hamlin, C. (1998) Public Health and Social Justice in the Age of Chadwick: Britain 1800-1854. Cambridge University Press, Cambridge, 1-15.

[96] Coughlin, S.S., Beauchamp, T.L. and Weed, D.L. (2009) Ethics and Epidemiology. Oxford University Press, Oxford, 5-6. https://doi.org/10.1093/acprof:oso/9780195322934.001.0001

[97] Evans, A. (2001) Benjamin Guy Babington: Founding President of the London Epidemiological Society. *International Journal of Epidemiology*, **30**, 226-230. https://doi.org/10.1093/ije/30.2.226

[98] Belongia, E.A. and Naleway, A.L. (2003) Smallpox Vaccine: The Good, the Bad, and the Ugly. *Clinical Medicine & Research*, 1, 87-92. https://doi.org/10.3121/cmr.1.2.87

[99] Jasanoff, S. (2012) The Politics of Public Reason. In: Rubio, F.D. and Baert, P., Eds., *The Politics of Knowledge*, Routledge, Oxford, 11-32.

[100] Zander, J. (2010) The Precautionary Principle in EU Law. In: *The Application of the Precautionary Principle in Practice: Comparative Dimensions*, Cambridge University Press, Cambridge, 76-151. https://doi.org/10.1017/CBO9780511779862.006

[101] Gill, N., Spencer, Y., Richard-Loendt, A., *et al.* (2013) Prevalent Abnormal Prion Protein in Human Appendices after Bovine Spongiform Encephalopathy Epizootic Large Scale Survey. *BMJ*, **347**, 15675.

[102] Royal Society of Public Health (2016) Waking up to the Health Benefits of Sleep. University of Oxford, Oxford.

[103] Nightingale F. (1859) Notes on Nursing: What It Is, and What It Is Not. Harrison, London, 27.

[104] Garcia, M.J. (2009) U.N. Convention against Torture (CAT): Overview and Application to Interrogation Techniques. CRS Report for Congress, 26 March 2009, 21.

[105] Ferriter, D. (2014) The Hooded Men. *The Irish Times*, 6 December 2014.

[106] Punch, J.L. and James, R.R. (2016) Wind Turbine Noise and Human Health: A Four-Decade History of Evidence That Wind Turbines Pose Risks. https://docs.wind-watch.org/Punch-James-Wind-Turbine-Noise-16-10-21.pdf

[107] http://aefweb.info/data/AUSWEA-2004conference.pdf

[108] https://qmail.qub.ac.uk/owa/redir.aspx?C=ypzjvMYSs8dqquKCSrN5yb_3wZ6Bkxxkz1VRQh9Eog32ntjUe2vUCA..&URL=http%3a%2f%2fwind2050.dk

[109] O'Sullivan, C. (2014) Senior Doctor Defends Wind Turbine Syndrome Conclusions. *The Irish Examiner*, 6 March 2014.

[110] Baliatsas, C., van Kamp, I., van Poll, R. and Yzermans, J. (2016) Health Effects from Low-Frequency Noise and Infrasound in the General Population: Is It Time to Lis-

ten? A Systematic Review of Observational Studies. *Science of the Total Environment*, **557-558**, 163-169.

[111] Spector, B. (1963) Jeremy Bentham 1748-1832: His Influence upon Medical Thought and Legislation. *Bulletin of the History of Medicine*, **33**, 25-42.

[112] U.S. Environmental Protection Agency (1974) Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety. Washington DC, 550/9-74-004.

[113] Hughes, G. (2012) The Performance of Wind Farms in United Kingdom and Denmark. Renewable Energy Foundation, London.

[114] Hughes, G. (2012) Why Is Wind Power So Expensive? An Economic Analysis. The Global Warming Policy Foundation, GWPF Report 7.

Effects of industrial wind turbine noise on sleep and health

Michael A. Nissenbaum, Jeffery J. Aramini[1], Christopher D. Hanning[2]

Northern Maine Medical Center, Fort Kent, Maine, USA, [1]Intelligent Health Solutions, Guelph, Ontario, Canada, [2]University Hospitals of Leicester NHS Trust, Leicester, UK

Abstract

Industrial wind turbines (IWTs) are a new source of noise in previously quiet rural environments. Environmental noise is a public health concern, of which sleep disruption is a major factor. To compare sleep and general health outcomes between participants living close to IWTs and those living further away from them, participants living between 375 and 1400 m (n = 38) and 3.3 and 6.6 km (n = 41) from IWTs were enrolled in a stratified cross-sectional study involving two rural sites. Validated questionnaires were used to collect information on sleep quality (Pittsburgh Sleep Quality Index — PSQI), daytime sleepiness (Epworth Sleepiness Score — ESS), and general health (SF36v2), together with psychiatric disorders, attitude, and demographics. Descriptive and multivariate analyses were performed to investigate the effect of the main exposure variable of interest (distance to the nearest IWT) on various health outcome measures. Participants living within 1.4 km of an IWT had worse sleep, were sleepier during the day, and had worse SF36 Mental Component Scores compared to those living further than 1.4 km away. Significant dose-response relationships between PSQI, ESS, SF36 Mental Component Score, and log-distance to the nearest IWT were identified after controlling for gender, age, and household clustering. The adverse event reports of sleep disturbance and ill health by those living close to IWTs are supported.

Keywords: Health, industrial wind turbines, noise, sleep

Introduction

Environmental noise is emerging as one of the major public health concerns of the twenty-first century.[1] The drive to 'renewable', low-carbon energy sources, has resulted in Industrial Wind Turbines (IWTs) being sited closer to homes in traditionally quiet rural areas to reduce transmission losses and costs. Increasing numbers of complaints about sleep disturbance and adverse health effects have been documented,[2-4] while industry and government reviews have argued that the effects are trivial and that current guidance is adequate to protect the residents.[5,6] We undertook an epidemiological study to investigate the relationship between the reported adverse health effects and IWTs among residents of two rural communities.

Methods

General study design

This investigation is a stratified cross-sectional study involving two sites: Mars Hill and Vinalhaven, Maine, USA. A questionnaire was offered to all residents meeting the participant-inclusion criteria and living within 1.5 km of an industrial wind turbine (IWT) and to a random sample of residents, meeting participant inclusion criteria, living 3 to 7 km from an IWT between March and July of 2010. The protocol was reviewed and approved by Institutional Review Board Services, of Aurora, Ontario, Canada.

Access this article online	
Quick Response Code:	Website: www.noiseandhealth.org
	DOI: 10.4103/1463-1741.102961
	PubMed ID: ***

Questionnaire development

Adverse event reports were reviewed, together with the results of a smaller pilot survey of Mars Hill residents. A questionnaire was developed, which comprised of validated instruments relating to mental and physical health (SF-36v2)[7] and sleep disturbance ((Pittsburgh Sleep Quality Index (PSQI)[8] and the Epworth Sleepiness Scale (ESS)[9]). In addition, participants were asked before-and-after IWT questions about sleep quality and insomnia, attitude toward IWTs, and psychiatric disorders. A PSQI score > 5 was taken to indicate poor sleep and an ESS score > 10 was taken to indicate clinically relevant daytime sleepiness.[1-4] Responses to functional and attitudinal questions were graded on a five-point Likert scale with 1 representing the least effect and 5 the greatest. The questionnaire is available on request.

Study sites and participant selection

The Mars Hill site is a linear arrangement of 28 General Electric 1.5 megawatt turbines, sited on a ridgeline. The Vinalhaven site is a cluster of three similar turbines sited on

I-23

a low-lying, tree-covered island. All residents living within 1.5 km of an IWT, at each site, were identified via tax maps, and approached either door-to-door or via telephone and asked to participate in the study (near group). Homes were visited thrice or until contact was made. Those below the age of 18 or with a diagnosed cognitive disorder were excluded. A random sample of households in similar socioeconomic areas, 3 to 7 km away from IWTs at each site, were chosen to participate in the study to allow for comparison (far group). The households were approached sequentially until a similar number of participants were enrolled. A nurse practitioner supervised the distribution and ensured completion of the questionnaires.

Simultaneous collection of sound levels during data collection at the participants' residences was not possible, but measured IWT sound levels at various distances, at both sites, were obtained from publically available sources. At the Mars Hill site, a four quarter study was conducted and data from all four seasons were reported by power outputs at several key measurement points. The measurement points were located on or near residential parcels. The predicted and measured levels at full power were derived from figures in the Sound Level Study, Compilation of Ambient and Quarterly Operations Sound Testing, and the Maine Department of Environmental Protection Order No. L-21635-26-A-N. Measured noise levels versus distance at Vinalhaven were taken over a single day in February 2010, with the turbines operating at less than full power in moderate-to-variable northwest winds aloft (R and R, personal communication, 2011). Table 1 shows the estimated and measured noise levels at locations of varying distances and directions from the turbines at Mars Hill and Vinalhaven.

Table 1: Measured and predicted noise levels at Mars Hill and Vinalhaven

Mars hill			
Distance to nearestturbine (m)[1]	Predicted max. LAeq 1 hr[1]	Measured noise LAeq 1 hr[1]	
		Average	Range
244	51	52	50 – 57
320	48	50	48 – 53
366	47	49	47 – 52
640	42	44	40 – 47
762	41	43	41 – 46
1037	39	41	39 – 45
1799	35	37	32 – 43

Vinalhaven		
Distance to nearest turbine (m)[2]	Measured Noise LAeq[2]	
	Trend Average	Range
152	53	51 – 61
366	46	38 – 49
595	41	39 – 49
869	38	32 – 41
1082	36	34 – 43

[1] Values read or derived from report figures; accuracy +/- 50 m and +/- 1 Db [2] Values obtained with wind turbine noise dominating the acoustical environment, two-minute measurements during moderate-to-variable northwest winds aloft (less than full power)

Data handling and validation

The Principal Investigator (Michael Nissenbaum, MD) did not handle data at any point in the collection or analysis phase. Questionnaire results were coded and entered into a spreadsheet (Microsoft Excel 2007). Each questionnaire generated over 200 data elements. The distance from each participant's residence to the nearest IWT was measured using satellite maps. The SF36-V2 responses were processed using Quality Metric Health Outcomes™ Scoring Software 3.0 to generate Mental (MCS) and Physical (PCS) Component Scores.

Data quality of the SF36-V2 responses was determined using QualityMetric Health Outcomes™ Scoring Software 3.0. All SF36-V2 data quality indicators (completeness, response range, consistency, estimable scale scores, internal consistency, discriminant validity, and reliable scales) exceeded the parameter norms. SF 36-V2 missing values were automatically accommodated by the scoring systems (99.9% questions were completed). No missing values were present for other parameters (ESS, PSQI, psychiatric and attitudinal observations, and demographics).

Statistical analysis

All analyses were performed using SAS 9.22.[10] Descriptive and multivariate analyses were performed to investigate the effect of the main exposure variable of interest (distance to the nearest IWT) on the various outcome measures. Independent variables assessed included the following: Site (Mars Hill, Vinalhaven); Distance to IWT (both as a categorical and continuous variable); Age (continuous variable); Gender (categorical variable). The dependent variables assessed included the following: Summary variables — Epworth Sleepiness Scale (ESS), Pittsburgh Sleep Quality Index (PSQI), SF36-V2 Mental Component Score (MCS), SF36-V2 Physical Component Score (PCS); Before and after parameters — sleep, psychiatric disorders (both self-assessed and diagnosed by a physician), attitude toward IWTs; and Medication use (both over-the-counter and prescription drugs). A P value of < 0.05 was regarded as being statistically significant.

Results

Study participants

Thirty-three and 32 adults were identified as living within 1500 m of the nearest IWT at the Mars Hill (mean 805 m, range 390 – 1400) and Vinalhaven sites (mean 771 m range 375 – 1000), respectively. Twenty-three and 15 adults at the Mars Hill and Vinalhaven sites respectively, completed the questionnaires. Recruitment of participants into the far group continued until there were similar numbers as in the near group, 25 and 16 for Mars Hill and Vinalhaven, respectively [Table 2].

Statistical results

The binomial outcomes were assessed using either the GENMOD procedure with binomial distribution and a logit link; or when cell frequencies were small (< 5), Fisher's Exact Test. When assessing the significance between variables with a simple score outcome (e.g., 1 – 5), the exact Wilcoxon Score (Rank Sums) test was employed using the NPAR1WAY procedure. Continuous outcome variables were assessed using the GENMOD procedure with normal distribution. When using the GENMOD procedure, age, gender, and site were forced into the model as fixed effects. The potential effect of household clustering on statistical significance was accommodated by using the REPEATED statement. Effect of site as an effect modifier was assessed by evaluating the interaction term (Site*Distance).

Participants living near IWTs had worse sleep, as evidenced by significantly greater mean PSQI and ESS scores [Table 3]. More participants in the near group had PSQI > 5 ($P = 0.0745$) and ESS scores > 10 ($P = 0.1313$), but the differences did not reach statistical significance. Participants living near IWTs were significantly more likely to report an improvement in sleep quality when sleeping away from home.

The near group had worse mental health as evidenced by significantly higher mean SF36 MCS ($P = 0.0021$) [Table 3]. There was no statistically significant difference in PCS ($P = 0.9881$). Nine participants in the near group reported that they had been diagnosed with either depression or anxiety since the start of turbine operations, compared to none in the far group. Nine of the 38 participants in the near group reported that they had been prescribed new psychotropic medications since the start of turbine operations compared with three of 41 in the far group ($P = 0.06$).

The ESS, PSQI, and SF36 scores were modeled against distance from the nearest IWT (Score = ln (distance) + gender + age + site [controlled for household clustering]), and the results are shown in Figures 1–3. In all cases, there were clear and significant dose-response relationships ($P < 0.05$), with the effect diminishing with increasing log-distance from IWTs. Log-distance fit the health outcomes better than distance. This was expected given that noise drops off as the log of distance. Measured sound levels were plotted against distance at the two sites on Figures 1-3.

Table 2: Demographic data of Mars Hill and Vinalhaven study participants

	Distance (m) from residence to nearest IWT (mean)			
Parameter	375 – 750 (601)	751 – 1400 (964)	3300 – 5000 (4181)	5300 – 6600 (5800)
Sample size	18	20	14	27
Household clusters	11	12	10	23
Mean age	50	57	65	58
Male / Female	10 / 8	12 / 8	7 / 7	11 / 16
Mean time in home[1]	14	21	30	24

[1] Years that study participants lived in the home

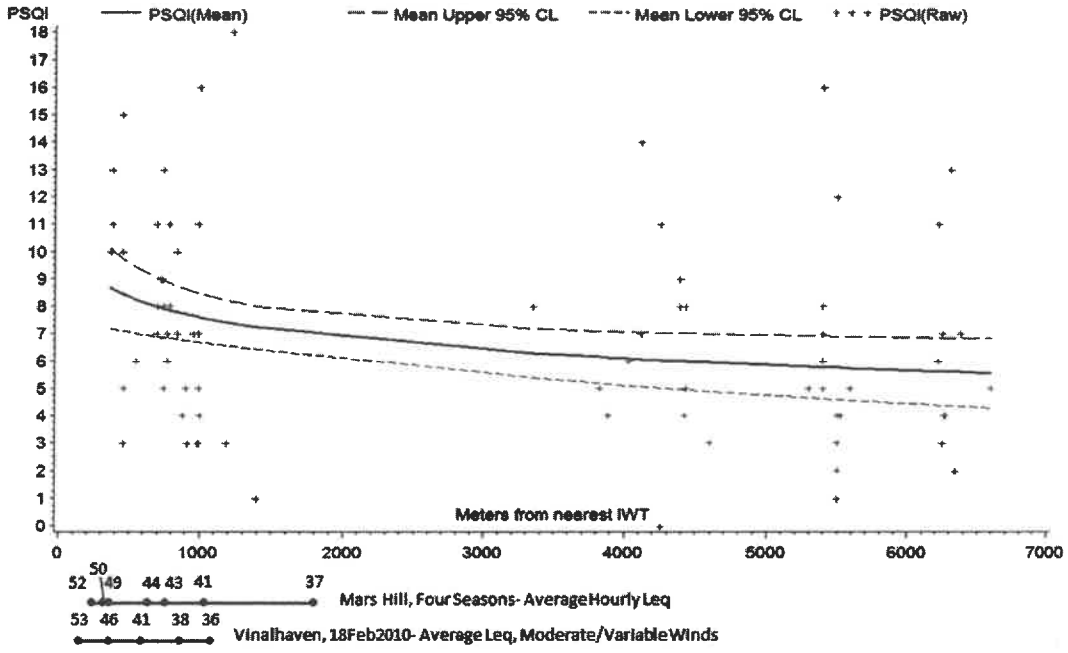


Figure 1: Modeled Pittsburgh Sleep Quality Index (PSQI) versus distance to nearest IWT (mean and 95% confidence limits) Regression equation: PSQI = ln (distance) + sex + age + site [controlled for household clustering]. Ln (distance) *p*-value = 0.0198

Table 3: Sleep and mental health outcomes of the study participants grouped by distance from the nearest IWT

	Distance (m) from residence to nearest IWT (mean)						
Parameter	375-750 (601)	751-1400 (964)	375-1400 (792)	3300-5000 (4181)	5300-6600 (5800)	3000-6600 (5248)	P-Value[1]
Mean PSQI[2]	8.7	7.0	7.8	6.6	5.6	6.0)	0.0461
% PSQI score >= 5[3]	77.8	55.0	65.8	57.1	37.0	43.9	0.0745
Mean ESS[4]	7.2	8.4	7.8	6.4	5.3	5.7	0.0322
% with ESS score >= 10[5]	16.7	30.0	23.7	14.3	7.4	9.8	0.1313
Mean worsening sleep score post IWTs[6]	3.2	3.1	3.1	1.2	1.4	1.3	< .0001
Improved sleep when away from IWTs	9 / 14	5 / 14	14 / 28	1 / 11	1 / 23	2 / 34	< .0001
% New sleep medications post IWTs	11.1	15.0	13.2	7.1	7.4	7.3	0.4711
New diagnoses of insomnia			2			0	
Mean SF36 MCS	40.7	43.1	42.0	50.7	54.1	52.9	0.0021
% Wishing to move away post IWTs	77.8	70.0	73.7	0.0	0.0	0.0	< .0001

[1] Testing difference of 375 – 1400 m group with 3000 – 6600 m group [2] Pittsburgh Sleep Quality Index [3] PSQI >= 5 is considered a "poor sleeper" [4] Epworth Sleepiness Scale [5] About 10 – 20 percent of the general population has ESS scores >= 10 [6] (New sleep problems + Worsening sleep problem)/2; Strongly Agree (5) - Strongly disagree (1)

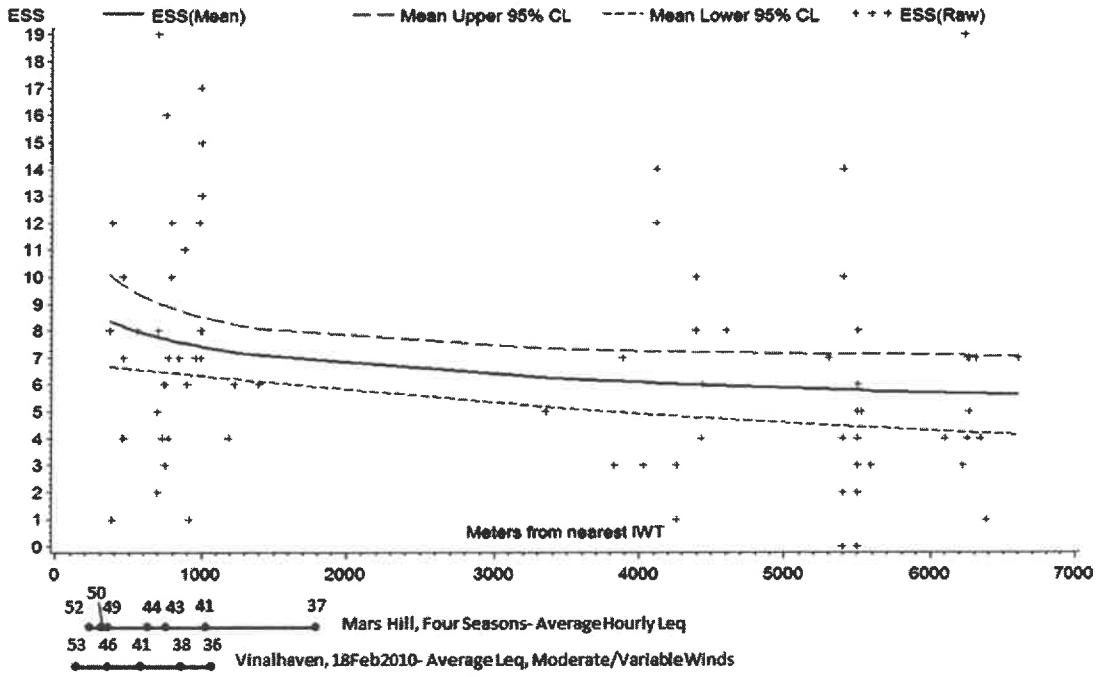


Figure 2: Modeled Epworth Sleepiness Scale (ESS) versus Distance to nearest IWT (mean and 95% confidence limits) Regression equation: ESS = ln (distance) + sex + age + site [controlled for household clustering]. ln (distance) p-value = 0.0331

There were no statistically significant differences between the near and far groups with respect to age, gender, or duration of occupation. In addition, Site, and Site*Distance were not significant, indicating that the modeled exposure-outcome relationships were similar across both sites.

Discussion

This study supports the conclusions of previous studies, which demonstrate a relationship between proximity to IWTs and the general adverse effect of 'annoyance'.[11-13] but differs in demonstrating clear dose-response relationships in important clinical indicators of health including sleep quality, daytime sleepiness, and mental health. The levels of sleep disruption and the daytime consequences of increased sleepiness, together with the impairment of mental health and the dose-response relationships observed in this study (distance from IWT vs. effect) strongly suggest that the noise from IWTs results in similar health impacts as other causes of excessive environmental noise[1].

The degree of effect on sleep and health from IWT noise seems to be greater than that of other sources of

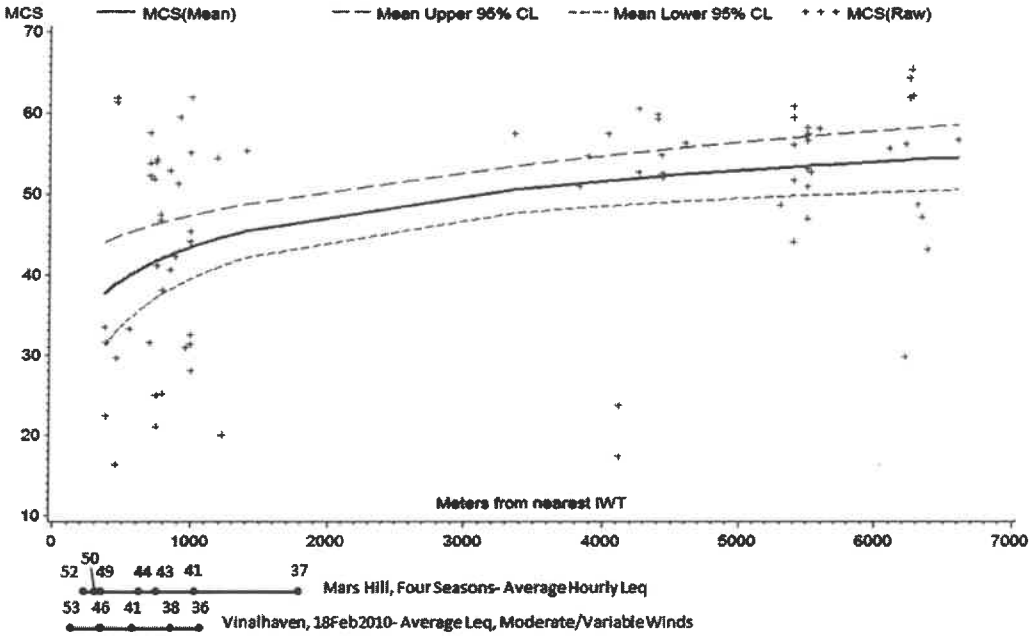


Figure 3: Modeled SF36 Mental Component Score (MCS) versus Distance to nearest IWT (mean and 95% confidence limits) Regression equation: MCS = ln (distance) + sex + age + site [controlled for household clustering]. ln (distance) p-value = 0.0014

environmental noise, such as, road, rail, and aircraft noise. Bray and James have argued that the commonly used noise metric of LAeq (averaged noise level adjusted to human hearing) is not appropriate for IWT noise, which contains relatively high levels of low frequency sound (LFN) and infrasound with impulsive characteristics.[14] This has led to an underestimation of the potential for adverse health effects of IWTs.

Potential biases

Reporting and selection biases in this study, if they existed, may have underestimated the strength of the association between distance to IWTs and health outcomes. Both Mars Hill and Vinalhaven residents gain financially from the wind projects, either through reduced electricity costs and / or increased tax revenues. The fear of reducing property values was also cited as a reason for downplaying the adverse health effects. Conversely, the possibility of legal action could result in symptoms being over stated. It was clear to the respondents that the questionnaire was directed at investigating adverse health effects potentially associated with IWT noise and no distractor questions were included. Nevertheless, given the large differences in reported adverse health effects between participants living within 1400 m and those living beyond 3300 m of an IWT, we do not believe that bias alone could have resulted in the differences demonstrated between the groups. In addition, the finding of strong dose-response relationships with log-distance, together with extensive sub-analyses using survey questions more and less likely to be influenced by bias demonstrating similar results, further support the existence of causative associations.

Visual impact and attitude are known to affect the psychological response to environmental noise.[11,15,16] At both sites, turbines are prominent features of the landscape and were visible to a majority of respondents; at Mars Hill, IWTs are sited along a 200 m high ridge, and Vinalhaven is a flat island. The visual impact on those living closest to turbines was arguably greater than on those living some distance away. Most residents welcomed the installation of IWTs for their proposed financial benefits and their attitudes only changed once they began to operate and the noise and health effects became apparent. Pedersen estimates that, with respect to annoyance, 41% of the observed effects of IWT noise could be attributed to attitude and visual impact.[11] The influence of these factors on other consequences, such as the health effects investigated in this study, remains to be determined. Even as these factors may have contributed to the reported effects, they are clearly not the sole mechanism and health effects are certain.

Mechanisms

A possible mechanism for the observed health effects is an effect on sleep from the noise emitted by IWTs. Industrial wind turbines emit high levels of noise with a major low frequency component. The noise is impulsive in nature and variously described as 'swooshing' or 'thumping'.[12] The character, volume, and frequency of the noise vary

with changes in wind speed and direction. Industrial wind turbine noise is more annoying than road, rail, and aircraft noise, for the same sound pressure, presumably due to its impulsive character.[12,15] Pedersen concludes that it is noise that prevents restoration, that those subjected to it are unable to find psychological recovery in their homes because of its intrusive nature.[16] Noise can affect sleep by preventing sleep onset or return to sleep following spontaneous or induced awakening. Clearly, attitude and psychological factors such as noise sensitivity may be important in influencing the ability to fall asleep, but it should be noted that noise sensitivity is, in part, heritable.[17] Noise also affects sleep by inducing arousals, which fragment sleep, reducing its quality and leading to the same consequences as sleep deprivation.[18] There is good evidence that road, rail, and aircraft noise induce arousals and lead to daytime consequences and there is no reason to suppose that IWT noise will not have a similar effect.[19-23] A recent study on the likelihood of different hospital noises that induce an arousal shows a considerable effect of sound character, with impulsive noises being more likely to induce an arousal.[24] It has also been shown that there is individual variability in the likelihood of an arousal in response to noise, which may be predicted from a spindle index, a measure of sleep quality.[25]

ESS assesses daytime sleepiness from the self-assessed propensity to fall asleep in different situations averaged over several weeks.[9] It is widely used in sleep medicine to assess daytime sleepiness, and scores in excess of 10 are deemed to represent clinically relevant excessive daytime sleepiness. If sleep is only disrupted occasionally, the ESS will not be affected, as the sleep deficit can be compensated on other nights. Changes in the ESS score observed in this study imply that sleep has been disrupted to a degree where compensation is not possible in at least some participants. PSQI also examines the sleep quality averaged over a period of weeks, scores in excess of 5 are deemed to represent poor quality sleep.[8] An individual's score will not be significantly affected by occasional disrupted nights, thus confirming the conclusions drawn from the ESS data. It is noteworthy also that significant changes in ESS and PSQI have been observed, despite the scatter in values indicative of the typical levels of impaired sleep found in the general population.[8,9]

Other mechanisms than sleep disruption cannot be excluded as an explanation for the psychological and other changes observed. Low frequency noise, and in particular, impulsive LFN, has been shown to be contributory to the symptoms of 'Sick Building Syndrome,' which has similarities with those reported here.[26,27] Salt has recently proposed a mechanism, whereby, infrasound from IWTs could affect the cochlear and cause many of the symptoms described.[28]

We assessed causality using a well-accepted framework.[29] Although the measured parameters (ESS, PSQI, and SF36) assess the current status, the evidence of the respondents is that the reported changes have followed the commencement of IWT operation. This is supported by the reported preferences of the residents; the great majority of those living within 1.4 km expressed their desire to move away as a result of the start of turbine operations. However, a study of the same population before and after turbine operation will be necessary to confirm our supposition. We believe that there is good evidence that a time sequence has been established. The association between distance to IWT and health outcome is both statistically significant and clinically relevant for the health outcomes assessed, suggesting a specific association between the factors. Given that this is the first study investigating the association between IWTs and a range of health outcomes, the consistency and replication to prove causation is limited. However, this study includes two different study populations living next to two different IWT projects. Despite these differences, the study site was not a significant effect modifier among any of the measured outcomes. In addition, adverse health effects similar to those identified in this study among those living near IWTs, have been documented in a number of case-series studies and surveys.[2-4,30] Finally, causal association can be judged by its coherence with other known facts about the health outcomes and the causal factor under study. The results of this study are consistent with the known effects of other sources of environmental noise on sleep.

The data on measured and estimated noise levels were not adequate to construct a dose-response curve and to determine an external noise level below which sleep disturbance will not occur. However, it is apparent that this value will be less than an average hourly LAeq of 40 dBA, which is the typical night time value permitted under the current guidance in most jurisdictions.

Conclusions

We conclude that the noise emissions of IWTs disturbed the sleep and caused daytime sleepiness and impaired mental health in residents living within 1.4 km of the two IWT installations studied. Industrial wind turbine noise is a further source of environmental noise, with the potential to harm human health. Current regulations seem to be insufficient to adequately protect the human population living close to IWTs. Our research suggests that adverse effects are observed at distances even beyond 1 km. Further research is needed to determine at what distances risks become negligable, as well as to better estimate the portion of the population suffering from adverse effects at a given distance.

Acknowledgments

We thank Dr. Carl Phillips, Rick James, INCE and Robert Rand, INCE for their review of the manuscript.

Address for correspondence:
Michael A. Nissenbaum, MD,
Northern Maine Medical Center, 194 E. Main Street,
Fort Kent, Maine 04743, USA
E-mail: mnissenbaum@att.net

References

1. World Health Organisation. Night noise guidelines for Europe. Copenhagen. 2009.
2. Frey BJ, Hadden PJ. Noise radiation from wind turbines installed near homes: Effects on health. 2007. [Last cited on 2010 July 18]. Available from: www.windnoisehealthhumanrights.com
3. Pierpont N. Wind Turbine Syndrome: A Report on a Natural Experiment. Santa Fe, (NM): K Selected Publications; 2009.
4. Krogh C, Gillis L, Kouwen N, Aramini J. WindVOiCe, a Self-Reporting Survey: Adverse Health Effects, Industrial Wind Turbines, and the Need for Vigilance Monitoring. Bull Sci Technol Soc 2011;31:334-45.
5. Colby WD, Dobie R, Leventhall G, Lipscomb DM, McCunney RJ, Seilo MT, *et al.* Wind Turbine Sound and Health Effects: An Expert Panel Review. American and Canadian Wind Energy Associations. 2009. [Last cited on 2011 Oct 31]. Available from: www.awea.org/learnabout/publications/upload/AWEA_and_CanWEA_Sound_White_Paper.pdf
6. National Health and Medical Research Council. Wind Turbines and Health: A rapid review of the evidence. Australian Government National Health and Medical Research Council. 2010. [Last cited on 2011 Oct 31]. Available from: www.nhmrc.gov.au/_files_nhmrc/publications/attachments/new0048_evidence_review_wind_turbines_and_health.pdf.
7. QualityMetric. SF-36v2 Health Survey. [Last cited on 2011 Oct 31]. Available from: www.qualitymetric.com/WhatWeDo/SFHealthSurveys/SF36v2HealthSurvey/tabid/185/Default.aspx.
8. Buysse DJ, Reynolds CF 3rd, Monk TH, Berman SR, Kupfer DJ. The Pittsburgh Sleep Quality Index (PSQI): A new instrument for psychiatric research and practice. Psychiatry Res 1989;28:193-213.
9. Johns MW. A new method for measuring daytime sleepiness: the Epworth sleepiness scale. Sleep 1991;14:540-5.
10. SAS/STAT 9.22 User's guide. SAS Institute Inc. 100 SAS Campus Drive Cary, NC 27513-2414 USA.
11. Pedersen E, van den Berg F, Bakker R, Bouma J. Response to noise from modern wind farms in The Netherlands. J Acoust Soc Am 2009;126:634-43.
12. van den Berg GP, Pedersen E, Bouma J, Bakker R. Project WINDFARMperception. Visual and acoustic impact of wind turbine farms on residents. FP6-2005-Science-and-Society-20. Specific Support Action Project no. 044628. 2008.
13. Shepherd D, McBride D, Welch D, Dirks KN, Hill EM. Evaluating the impact of wind turbine noise on health-related quality of life. Noise Health 2011;13:333-9.
14. Bray W, James R. Dynamic measurements of wind turbine acoustic signals, employing sound quality engineering methods considering the time and frequency sensitivities of human perception. Proceedings of Noise-Con; 2011, July 25-7;Portland, Oregon.
15. Pedersen E, Waye KP. Perception and annoyance due to wind turbine noise--a dose-response relationship. J Acoust Soc Am 2004;116:3460-70.
16. Pedersen E, Persson Waye K. Wind turbines – low level noise sources interfering with restoration? Environ Res Lett 2008;3:1-5.
17. Shepherd D. Wind turbine noise and health in the New Zealand context. In: Rapley B, Bakker H, editors. Sound, Noise, Flicker and the Human Perception of Wind Farm Activity. Palmerston North, New Zealand: Atkinson and Rapley Consulting Ltd; 2010. p. 13-63.
18. Meerlo P, Sgoifo A, Suchecki D. Restricted and disrupted sleep: effects on autonomic function, neuroendocrine stress systems and stress responsivity. Sleep Med Rev 2008;12:197-210.
19. de Kluizenaar Y, Janssen SA, van Lenthe FJ, Miedema HM, Mackenbach JP. Long-term road traffic noise exposure is associated with an increase in morning tiredness. J Acoust Soc Am 2009;126:626-33.
20. Basner M, Glatz C, Griefahn B, Penzel T, Samel A. Aircraft noise: Effects on macro- and microstructure of sleep. Sleep Med 2008;9:382-7.
21. Basner M. Nocturnal aircraft noise exposure increases objectively assessed daytime sleepiness. J Sleep Res 2008;17:Suppl 1;P512.
22. Elmenhorst E, Basner M. Effects of Nocturnal Aircraft Noise (Volume 5): Performance. Institute of Aerospace Medicine of the German Aerospace Center (DLR). Cologne. DLR-Forschungsbericht 2004-11. 2008.
23. Elmenhorst EM, Elmenhorst D, Wenzel J, Quehl J, Mueller U, Maass H, *et al.* Effects of nocturnal aircraft noise on cognitive performance in the following morning: dose-response relationships in laboratory and field. Int Arch Occup Environ Health 2010;83:743-51.
24. Solet JM, Buxton OM, Ellenbogen JM, Wang W, Carballiera A. Evidence-based design meets evidence-based medicine: The sound sleep study. Concord, CA: The Center for Health Design. 2010. [Last cited on 2011 Oct 31]. Available from: http://www.healthdesign.org/sites/default/files/Validating%20Acoustic%20Guidelines%20for%20HC%20Facilities_Sound%20Sleep%20Study.pdf.
25. Dang-Vu TT, McKinney SM, Buxton OM, Solet JM, Ellenbogen JM. Spontaneous brain rhythms predict sleep stability in the face of noise. Curr Biol 2010;20:R626-7.
26. Niven RM, Fletcher AM, Pickering CA, Faragher EB, Potter IN, Booth WB, *et al.* Building sickness syndrome in healthy and unhealthy buildings: An epidemiological and environmental assessment with cluster analysis. Occup Environ Med 2000;57:627-34.
27. Persson Waye K, Rylander R, Benton S, Leventhall HG. Effects on performance and work quality due to low frequency ventilation noise. J Sound Vib 1997;205:467-74.
28. Salt A, Kaltenbach J. Infrasound From Wind Turbines Could Affect Humans. Bull Sci Technol Soc 2011;31:296-302.
29. Susser M. Criteria of Judgment. In: Causal Thinking in the Health Sciences - Concepts and Strategies of Epidemiology. New York: Oxford University Press; 1973.
30. Phillips C. Properly Interpreting the Epidemiologic Evidence About the Health Effects of Industrial Wind Turbines on Nearby Residents. Bull Sci Technol Soc 2011;31:303-15.

How to cite this article: Nissenbaum MA, Aramini JJ, Hanning CD. Effects of industrial wind turbine noise on sleep and health. Noise Health 2012;14:237-43.

Source of Support: Nil. **Conflict of Interest:** None declared.

Why Does Egg Mortality Increase Near a New Wind Industry?

HENNING THEORELL, MD. SPEC. INTERNAL MEDICINE, *HENNING.THEORELL@HOTMAIL.COM*

MARIA VEMDAL, M. SC.. INDUSTRIAL ENGINEERING, *MVEMDAL@GMAIL.COM*

Noise

animal health.

Published in "Svensk Veterinärtidning" No 5 June 2024 Vol. 75

https://www.svenskveterinartidning.se/wp-content/uploads/2024/06/SVT2405.pdf
(please answer "yes" to initial question to access the publication)

Introduction

In Sweden, 2 million eggs are produced annually, with many hobby chicken owners supplementing established suppliers. The Facebook group "Vi som har höns" (We Who Have Chickens) has 42,000 members, and "Höns och fjäderfä" (Chickens and Poultry) has 92,000 members. Associations like the Swedish Land Chicken Association and other breeding societies are committed to preserving and raising chicken breeds, reflecting the significant interest in poultry farming and its importance for food production and cultural heritage in Sweden.

In addition to domestic chickens, Sweden has a rich fauna of forest birds such as capercaillie, black grouse, ptarmigan, hazel grouse, pheasant, and guinea fowl.

At a permaculture farm in Småland, egg mortality has markedly increased since a new wind industry began operating only 1000 meters from the farm center. This is concerning given the massive rollout of wind power planned in southern Sweden. The farmers referenced in this article have tried to investigate the phenomenon to the best of their ability, but controlled studies and measurements are needed to better understand the causes.

This article summarizes the studies already conducted in relevant research areas but primarily aims to highlight the importance of more controlled studies as soon as possible before the risks materialize and both wild and domestic poultry's egg mortality becomes catastrophically high.

Background

A significant change within the wind power industry is the marked increase in the size of wind turbines (both height and rotor diameter) since 2018. Despite this increase, guidelines for audible noise from wind turbines have not been updated accordingly. Moreover, there are still no limits for low-frequency noise and infrasound, which is a serious deficiency. This is despite a thorough modeling study conducted in 2014.

In the environmental impact assessments (EIM) carried out before applying for permits for environmentally hazardous activities (wind turbines), no consideration is given to the effects of ground geology or ground vibrations on people or local fauna. Only the distance from wind turbines to lekking sites for forest birds is considered, i.e., the collision risk.

I-24

Interestingly, there is no clear guidance on the vibrations that large-scale wind power can generate. This is despite it being well-documented that vibrations can affect cells at the chromosomal level. This raises questions about whether wind farms can have a similar impact on wildlife and humans nearby. An illustrative example of this is the restrictions for female helicopter pilots who are prohibited from flying during pregnancy due to the risks of vibrations affecting the fetus. This shows the serious need for guidelines and regulations that consider the potential health risks associated with vibrations from wind industries.

For animal husbandry, there are no guidelines at all, and with the aggressive rollout of large-scale wind power in southern Sweden, there could be extensive and irreversible damage to animal husbandry and, in the long term, food production.

Case Study

The Schwere family in Ljungbyholm maintains a hobby flock with five different breeds. The normal hatch rate from 2009 to 2020 has been at least 95% successful hatches after 21 days of incubation.

In 2021, a new wind power industry with 12 turbines of 4.5 MW each began operating about 1000 meters from the farm center. During the years 2021-2023, the hens stopped incubating after 16 days, leaving all the eggs dead. Even the few hens that went into the forest returned alone instead of returning with chicks as in previous years.

The family's adult son lives 3 kilometers from the new wind industry and also keeps free-range chickens, mostly of the Blomme breed. From 2009 to 2023, the hatching success rate has been at least 90%. In 2022, the son moved three of these hens and a rooster to his parents' chicken yard, 950 meters from the nearest wind turbine. These hens also stopped incubating after 16 days, leaving dead eggs.

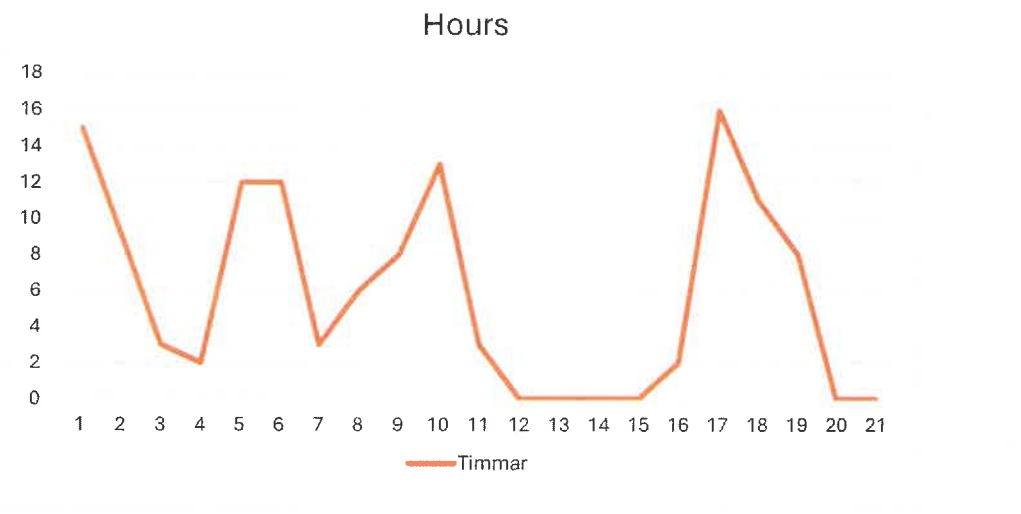
Table 1. Egg Mortality in the Coop During the Period May 1-21, 2023

Using a Willab incubator, mostly with the Skåne Blomme breed:

Location	Distance (meters)	Total	Dead	Alive	Mortality %
Chicken house 1	950	49	49	0	100
Closet house 1	1006	22	17 +1	4	83
Coop behind house 1	1025	10	6	4	60
Closet house 2	3160	40	2	38	5

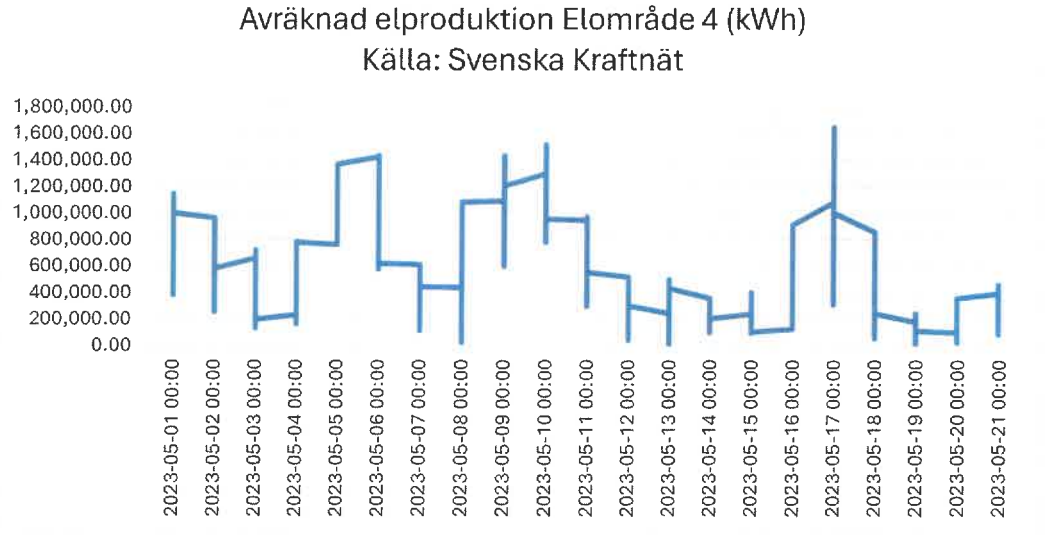
Note: +1 indicates hatched malformed and died.

Table 2. SMHI Weather Data with Wind Speeds During the Period May 1-21, 2023



| Hours with wind speed >5 m/s distributed over calendar days in May 2023. Note the peak recordings on the days 1-2, 5-6, 10, and 17-19, which coincide with critical developmental stages for chicken eggs.

Table 3. Svenska Kraftnät's Electricity Production at the Nearest Measuring Station During the Relevant Period



The tables indicate a significant correlation between wind speeds and peak loads, which likely generates the most tower and foundation vibrations in the ground.

Egg Mortality

Egg mortality in free-range chickens is a complex phenomenon influenced by multiple factors. It is known that hens that do not incubate properly may leave their eggs unattended, which can lead to increased egg mortality, and increased stress levels can reduce hens' inclination to incubate the eggs. Stress levels are naturally affected by disturbances or threats in the environment.

Insufficient nutrition or an unbalanced diet can affect both egg production and egg quality, increasing the risk of egg mortality. In the case of the current observation, this factor has been constant as the same individuals were only moved, and the feeding remained the same.

The age of the hens naturally affects reproduction. Older hens may experience reduced fertility and egg quality compared to younger individuals. Inbreeding is another factor that can have negative consequences as it can lead to genetic defects and reduced survival of the chicks.

Infectious diseases pose a significant risk to hens' reproduction. Bacterial infections such as E. coli and salmonella, as well as viral diseases like avian influenza and Marek's/herpesvirus, can cause egg mortality and malformations in chicks. Parasites such as roundworms, coccidia, and chicken mites can also negatively affect hens' reproductive health.

Therefore, it is important to conduct controlled trials with regular veterinary checks and appropriate preventive measures both before and during the course of a study.

The question is how much environmental factors such as noise and vibrations affect egg mortality in chickens. A review of the studies conducted in the area indicates an impact, but studies investigating the effects of ground vibrations combined with low-frequency noise on hens' reproductive health are lacking.

Previous Research

Research has shown that vibrations during days 5-8 of the development of chicken eggs can inhibit oxygen uptake in the allantois membrane[i]. Laboratory experiments conducted in the USA in 1990 and 1994 have shown that vertical vibrations on chicken eggs increase mortality and malformations, especially at frequencies between 20-30 Hz and acceleration amplitudes of 0.25-1.5G[ii iii iv]. The same frequencies and amplitudes increase mortality by up to 48% in guinea fowl eggs[v].

It has been clarified that it is not low-frequency sound itself that affects but a combination with whole-body vibrations with an acceleration amplitude of 1.16G and at 12 Hz (corresponding to the resonant frequency of a standing human) that is required to increase sister chromatid exchange in both human and mouse lymphocytes[vi vii].

At a seismological measurement station in Askome in Halland, near wind turbines, acceleration amplitudes with weak peaks of 0.0033 nm/s² in the range of 0.3-10 Hz and from 12-39 Hz[viii] have been recorded, strongly correlating with the performance of the wind turbines.

In Ontario, rapid minute-long acceleration peaks at frequencies of 10-20 Hz were recorded at a distance of 600 meters from a facility with 4 wind turbines of 2-3MW[ix].

Airborne noise emissions with cylindrical propagation at frequencies from 20-100 Hz decrease by 3 dB per doubling of distance, and air absorption decreases by 0.02-0.05 dB per km, i.e., negligible difference between the farms' exposure[x].

Together with reports showing that whole-body vibration in addition to airborne noise is required for chromosome impact, this may indicate that ground vibration frequencies and

amplitudes from tower foundations generated at a distance of 1000 meters are harmful to eggs but not harmful when the distance increases to 3000 meters[xi].

It has been scientifically proven that noise and vibrations from wind turbines cause stress in various animals, evidenced by elevated cortisol levels in the serum and hair follicles of geese and badgers when they are close to wind turbines[xii xiii]. It remains unclear whether this stress can be attributed to auditory perception affecting neural pathways leading to stress centers in the amygdala and hypothalamus/pituitary gland, or if it can be ascribed to ground vibrations. Reports indicate that badgers abandon their dens, moose and reindeer flee from wind industries during operation and return when the wind is still, and birds vacate areas with wind power installations, both domestically and internationally.

A 2008 report on increasing egg mortality and malformations following the commissioning of a wind industry in Wisconsin[xiv] suggests potential links between airborne wind turbine noise and/or ground vibrations from tower bases. This is further supported by WG Ackers' compilation of international observations during 2016-2019, highlighting the impact of wind farms on human and animal health[xv].

Vibrations disrupt laminar capillary blood flow in all tissues, leading to turbulent flow and damage to the endothelium's nitric oxide (NO) release. This results in hypoxia and the release of tissue-damaging free radicals. Mechanoreceptors connecting cells have been shown to initiate pericapillary fibrous tissue deposition and revascularization. These pressure and vibration-sensitive cation channels in cell membranes, Piezo 1 and Piezo 2, were first identified by Coste, Papapoutian, and colleagues in 2010 in neuroblastoma cells. This newly discovered receptor group, which includes position, pain, temperature, and itch receptors, earned Patapoutian and Julius the Nobel Prize in Medicine in 2021. Activation triggers perivascular collagen and elastin synthesis, providing small vessel protection[xvi].

These vascular changes, along with electron microscopy-detectable tissue damage related to exposure time and intensity of IS/LFN exposure and whole-body vibration, have been documented in various organs in mammals and humans[xvii xviii].
However, the vascular beds of birds are not as well documented.

An Israeli company has successfully altered the sex ratio of chickens from 50/50 to 5 roosters and 95 hens using mRNA promoters and low-frequency sound during days 4-6 in the incubator[xix].
The impact of low-frequency sound on chromosomes is undeniable. Studies have shown that male Z chromosomes tend to accumulate more mutations compared to female W chromosomes[xx].

The question remains: what happens to both wild and domestic birds when exposed to both noise and vibrations in their habitat? There are no studies on eggs in wild bird nests to assess whether bird populations are decreasing due to chromosomal disturbances or if birds are choosing to flee. Is bird fertility affected by stress on hormone-regulated nerve centers, or are the eggs harmed by detrimental vibrations?

Conclusion

Science data and observations indicate the need for further research to understand how ground vibrations combined with low-frequency noise can affect the reproductive health of hens.

At the time of writing, industries with much larger wind turbines than those currently operational are being established. The turbines planned for installation in the coming years are of the size 6-10 MW each, which will likely generate even stronger ground vibrations.

It is important not to downplay the potential harm of wind power emissions to the biology of all living organisms, and thus interdisciplinary research collaboration is needed between acousticians, geotechnicians, medical doctors, veterinarians, ornithologists, infectious disease specialists, pathologists, and chromosome researchers.

---

[i] Ljud från vindkraftverk, modellvalidering-mätning Slutrapport Energimyndigheten projekt 32437-1. Conny Larsson 2014-12-30

[ii] Lizurek, Piotr. 1973. The effect of low frequency mechanical vibration on oxygen uptake by the chick embryo during embryogenesis. Acta physiology of Poland. XXIV:4

[iii] Effect of Vibration Frequency and Acceleration Magnitude of Chicken Embryos on Viability and Development Phase I By Linda C. Taggart Nabih M. Alem Helen M. Frear Biodynamics Research Division EDr T i C, November 1990 USAARL, Fort Rucker, Alabama 36362-5292

[iv] Effect of Vibration Frequency and Amplitude on Developing Chicken Embryos By Samuel G. Shannon Al W. Moran Linda C. Shackelford and Kevin T. Mason ELECTED DEC J 2 1994; Aircrew Protection Division 19941205 086 October 1994USAARL Fort Rucker Alabama 36362-0577

[v] Sabo, Vladimir, Boda, Koloman, and Peter, Vladimir. 1982. Effect of vibration on the hatchability and mortality of embryoes of Japanese quails. Polnohospodarstvo 28,6

[vi] Sister chromatid exchange analysis in workers exposed to noise and vibration M.J. Silva, A. Carothers, N. Castelo Branco, A. Dias, M.G. Boavida a Mutation Research 369 (1996) 113-121

[vii] Low frequency noise and whole-body vibration cause increased levels of sister chromatid exchange in splenocytes of exposed mice. M J Silva 1, A Dias, A Barreta, P J Nogueira, N A A Castelo-Branco, M G Boavida. Teratog Mutagen 2002;22(3):195-203

[viii] Lund, B., Schmidt, P., Shomali, Z.H., Roth, M. (2021) The Modern Swedish National Seismic Network: Two Decades of Intraplate Microseismic Observation, Seismol. Res. Lett., 92, 1747-1758,

[ix] The Industrial Wind Turbine Seismic Source M. WEST, P. GEOPH., B.SC., GDM WINDSOR, ONTARIO. CSEG RECORDER JUNE 2019

[x] Luftabsorption ref.: SNV Rapport 6241 (2010) (dB/km)

[xi] Seismic radiation from wind turbines: Observations and analytical modeling of frequency-dependent amplitude decays. Fabian Limberger, Michael Lindenfeld, Hagen Deckert, and Georg Rümpker. Institute of Geosciences, Goethe-University Frankfurt, Germany. Institute for Geothermal Resource Management, Germany. Solid Earth, 12, 1851–1864, 2021. https://doi.org/10.5194/se-12-1851-2021

[xii] Preliminary studies on the reaction of growing geese (Anser anser f. domestica) to the proximity of wind turbines. J. Mikołajczak, S. Borowski, J. Marć-Pieńkowska, G. Odrowąż-Sypniewska, Z. Bernacki, J. Siódmiak, P.

Szterk. Polish Journal of Veterinary Sciences Vol. 16, No. 4 (2013), 679–686

[xiii] WIND TURBINES CAUSE CHRONIC STRESS IN BADGERS (MELES MELES) IN GREAT BRITAIN. Roseanna C. N. Agnew, Valerie J. Smith, and Robert C. Fowkes. Royal Veterinary College, Zoological Society of London, Scottish Oceans Institute, University of St. Andrews. Journal of Wildlife Diseases, 52(3), 2016, pp. 000–000, Wildlife Disease Ass. 2016

[xiv] The BPRC Research Nerd in Fond du Lac County, Home in a wind farm with a 1000 foot setback: Fond du Lac County WI, Life in a wind farm, We Energies, property values, wind farm birds Posted on Wednesday, October 28th , 2009 at 09:09PM

[xv] Some Of The Case Studies That Have Convinced Me That Industrial Wind Turbines Make People Sick, Which Supports My Belief That We Can Prove In A Court Of Law That These Wind Turbines Are Causing Annoyance and Illnesses. By: William G. Acker Acker & Associates Prepared: December 27th 2015 through Feb. 18th 2019

[xvi] Coste B, Mathur J, Schmidt M, Earley TJ, Ranade S, Petrus MJ, Dubin AE, Patapoutian A. Piezo1 and Piezo2 are essential components of distinct mechanically activated cation channels. Science 2010:330: 55-6

[xvii] Mariana Alves-Pereira. Bruce Rapley. Huub Bakke. Rachel Summer. Infrasound and Low frequency Noise; A Public Health Nightmare. Universida de Lusofonia. Massey University. New Zealand. ICBEN Glasgow. Scotland. Sept 22. 2017

[xviii] Impairment of the Endothelium and Disorder of Microcirculation in Humans and Animals Exposed to Infrasound due to Irregular Mechano-Transduction Ursula Maria Bellut-Staeck Independent Scientist, Berlin, Germany. J. of Biosciences and Medicines > Vol.11 No.6, June 2023 DOI: 10.4236/jbm.2023.116003

[xix] We aren't playing God": An Israeli development can change the sex of chicken embryos. Israeli Startup SOOS Technology CEO Yael Alter. Interview by Ida ben Tovim in GEEKTIME Aug 28th 2022

[xx] Emergence of male-biased genes on the chicken Z-chromosome: Sex-chromosome contrasts between male and female heterogametic systems. Hans Ellegren[1] Genome Res. 2011 Dec; 21(12): 2082–2086.
doi: 10.1101/gr.119065.110

Arbeitsmedizin/Sozialmedizin/Umweltmedizin
Occupational Medicine/Social Medicine/ Environmental Medicine

July 1, 2021 | Published in Issue 07-2021 | Print Preview

Infrasound from technical installations: Scientific basis for an assessment of health risks

Background: The pathogenic potential of infrasound from technical sources is significantly underestimated by the public and politicians. Wind turbines are the most common emitters and their rapid rollout means that an increasing number of residents are affected by far reaching pressure pulses.

Methods: Research findings relating to causal mechanisms of infrasound are compiled and examined for indications of adverse effects on health.

Results: Infrasound is perceived as a stressor and is met with adaptive and defensive responses. Points of attack for toxic effects can be identified a) at cellular level, where membrane processes react with particular sensitivity. This leads to disruption of the microcirculation, muscle contraction and neuronal signal transmission. b) In the cardiovascular system, the effects mentioned in a) cause a reduction in the efficiency of the myocardial muscle coupled with centrally mediated bradycardia, hypertension and reduced cardiac output. c) The signal receptors for the balance system receive infrasound as interference and produce a clinical picture similar to motion sickness. d) In the brain, infrasound is unconsciously perceived in areas that are involved in the control of autonomic functions (incl. respiratory frequency and blood pressure) and in emotional control.

Conclusions: The findings available today substantiate a fundamental health risk for people exposed to infrasound. The steep pressure pulses of actual emissions have been disregarded by government-initiated studies of wind turbines to date. There is a need for adequate safety margins and further research in order to establish dose (energy)-response curves for the cardinal symptoms.

Keywords: infrasound – wind turbine – pressure pulse – adverse effects on health

U Arbeitsmed Sozialmed Umweltmed 2021; 56: 420–430

W. Roos (Prof. Dr. em.) [1]

C. Vahl ***(Prof. Dr. em.)*** [2]

1 Institute of Pharmacy (Director: Prof. Dr. Karsten Mäder), University of Halle-Wittenberg

2 Department of Cardiovascular Surgery (Director: Prof. Dr. Hendrik Treede), University Medical Center Mainz

(received on December 4, 2020, accepted on May 10, 2021)

I-25

Introduction

Medical aspects have so far not received due attention in the debate about the acceptance of wind turbines. This is particularly true for long-range acoustic effects, which are essentially based on infrasound, an inaudible emission from these turbines. Significant intensities of infrasound emitted by wind turbines have been measured several kilometers away (e.g., Palmer 2017; Pilger and Ceranna 2017). There has long been evidence that complaints from residents reporting severe sleep disturbances and the resulting damage during wind turbine operation are caused by the infrasound component of the emissions (e.g., Bahtarian and Beaudry 2015; Stelling 2015; Kaula 2019). On the other hand, there is no shortage of official statements that attribute only very low intensities to infrasound from wind turbines even at a distance of a few hundred meters and that negative effects on humans are not scientifically proven (e.g., LUBW 2016; UBA 2016; Maijala 2020).

This situation reflects not only a problem with wind energy, but also a lack of availability and knowledge of scientifically sound data on the effects of infrasound on biological systems. This prompts the authors of this article to compile research results on the specific effects of technical infrasound on humans and mammals and to investigate them for verifiable or at least plausible indications of health impairment. The goal is a causal analysis of infrasound effects. Can a potential stressor with defined properties (frequency, sound pressure, duration of effect) be attributed to measurable changes in a defined object (cell, tissue, organ) or at defined sites of action in the organism? Wherever possible, standards of experimental medicine and pharmacology were applied, particularly recognized and documented measurement procedures, blind and reference values, and comprehensible statistical transparency. Usable data exist for cells and tissues, the cardiovascular system and other organs, the signaling systems of the sense of hearing and balance, and selectively activatable brain areas.

This approach differs from epidemiological studies on the annoyance or acceptance of infrasound sources by residents. These, for example, look for correlations between expressed or documented complaints and the distance from wind turbines or measured sound pressure levels. However, the (presumably) involved infrasound components are usually not separated from audible sound, for example, low-frequency sound. Since infrasound is perceived via fundamentally different signaling pathways (see below) and very likely triggers different primary reactions than audible sound, specific causal statements about infrasound effects are hardly possible in this way. One example is the extensive work by Micheaud et al. (2016). The sound pressures measured there and used for a correlation analysis were C-filter weighted (dBC), meaning frequencies below 8 Hz were excluded, even though the infrasound pulses from the wind turbines investigated here are emitted in this range (➥Fig. 1). Further examples follow in the text.

Sound refers to mechanical waves in an elastic medium (solid, liquid, or gas). The inaudible frequency range below 20 Hz is called infrasound. It is characterized by long wavelengths (e.g., 343 m at 1 Hz in air at 20 °C) that can hardly be insulated by conventional building materials. In nature, such waves are emitted when parts of the Earth's crust vibrate, for example, during earthquakes and volcanic eruptions, by ocean waves, thunder, or wind in forests or meadows. Technological civilization has created numerous new sources of infrasound, including large-scale industrial facilities, road vehicles, and aircraft. While heterogeneous sources from nature generally emit low-frequency noise that is not perceived as disturbing, technical installations often emit pulsed vibrations that are suspected of causing damage to the human body upon prolonged exposure (Stelling 2015; Palmer 2017). This applies, among others, to wind turbines, the most widespread emitters of technical infrasound. The passage of the rotor blades over the mast leads to contractions of the air column between them and thus to pulses (maxima and minima) of air pressure, the frequency of which is determined by the rotational speed of the turbine. The fundamental vibration of the air column and the

associated harmonics generate a typical frequency pattern that propagates at the speed of sound (see Fig. 1 at the bottom of this article from the sidebar).

As a measure of the energy transmitted by sound waves, the sound pressure is usually expressed in Pascal.

It is used and expressed in the logarithmic unit decibels (dB), with 20 µPascals as the zero point. When measuring audible sound, sound pressure levels are usually weighted to approximate human hearing (A-weighting, dBA). The inaudible frequency range below 20 Hz is filtered out. To assess infrasound, the objectively present, biophysically effective sound pressure levels in the range below 20 Hz are required. The sound pressure levels quoted below are always unweighted.

Effects of Infrasound at the Cellular Level

Disruption of Membrane Processes

The mechanical energy transported by sound waves manifests itself in alternating movements, condensations, and rarefactions of particles in the sound-carrying medium. It is therefore obvious that a critical sound pressure can trigger changes in biological structures, with membranes being particularly sensitive due to their biophysical properties. Due to the low attenuation and great penetration depth, this is particularly to be expected for infrasound.

Indeed, the gradual breakdown of the blood-retinal barrier was demonstrated in rats during the application of high infrasound pressures (8 Hz, 130 dB). This process was monitored over several days using the diffusion marker La3+ and increased with exposure time (Qui et al. 2002). The membrane permeability of rat erythrocytes was also increased after infrasound exposure (13–30 Hz, 114 dB) (Sharipova 2013).

Biophysical processes at membranes form the cellular basis for cardiac muscle contraction and its control. They occur at the cell membrane of cardiomyocytes and intracellularly at the sarcoplasmic reticulum and mitochondria. Periodic changes in calcium concentration play a key role: During systole, calcium is released from the sarcoplasmic reticulum and activates the cardiomyocyte contractile apparatus through electromechanical coupling. During diastole, calcium is pumped back from the intracellular space into the sarcoplasmic reticulum. An increase in the diastolic intracellular calcium level is characteristic of the end stages of certain heart diseases (dilated cardiomyopathy, heart failure).

In this context, the results of Chaban et al. (2020) are of considerable importance: A highly significant, negative inotropic effect of infrasound (from 100 dB) was demonstrated on isolated, beating human myocardial tissue. For every 10 dB increase in sound pressure level, there was a 9% reduction in contractile force. A strength of this study lies in the precisely defined experimental conditions. The infrasound-exposed cell preparation and the control cells were derived from the same human, thus eliminating individual differences as a confounding factor. In the isolated perfused preparations, the conduction pathway that precedes contraction in the intact myocardium was excluded, and endocrinological mediators were absent. Therefore, electromechanical coupling in the contractile apparatus of the cardiomyocytes must be assumed to be the target of infrasound. A diastolic increase in the intracellular Ca2+ concentration is likely the immediate cause of the reduction in contractile force. The fact that the observed effect occurred after just one hour of exposure indicates the high sensitivity of the contraction process to the stressor (➥Fig. 2).

Human and mammalian cell cultures offer suitable study subjects for the investigation of cellular stress management. Infrasound finds various targets there and interferes, for example, with the defense against

oxidative stress (Pei et al. 2013). Changes in the intracellular Ca2+ concentration are often an indicator of interference with stress defense.

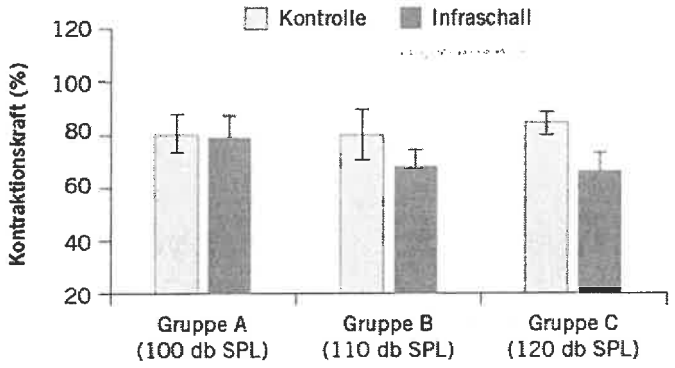


Fig. 2: Effect of infrasound on the contractile force of cardiomyocytes. Muscle preparations (3 × 0.5 × 0.5 mm) were prepared from right atrium tissue samples (waste material from bypass surgery), fixed under the microscope using microforceps, and perfused with Krebs-Henseleit buffer. After equilibration of the preparations, contractions were elicited by successive electrical pulses (4 ms each), the strength of which was measured electronically. Two samples from a total of 18 patients were examined under identical conditions. One of these samples was exposed to 16 Hz sinus infrasound via a loudspeaker for 1 h, while the other served as a control. The patients were between 18 and 90 years old and free of severe cardiomyopathies or malformations. The data show the measured contraction force before and after infrasound treatment; the differences between infrasound and control groups are significant with p = 0.0006. Details can be found in Chaban et al. (2020).

Fig. 2: Effect of infrasound on the contractile force of cardiomyocytes. Tissue samples from the right atrium (waste material from bypass operations) were used to prepare muscle specimens (3×0.5×0.5 mm) that were fixed under the microscope with micro-tweezers and perfused with Krebs-Henseleit buffer. Following sample preparation and equilibration, contractions were triggered by consecutive electrical impulses (4 ms each) whose strength was measured electronically. Two samples each from a total of 18 patients were examined under identical conditions. One was exposed to 16 Hz infrasonic sinusoidal waves through a speaker for an hour, whilst the other served as a control sample. The patients were between 18 and 90 years old and free of severe cardiomyopathies or malformations. The data show the contractile force measured before and after infrasound treatment; the differences between the infrasound group and control group are significant with p = 0.0006. Details in Chaban et al. (2020)

Apotosis (programmed cell death)

Increases in cytoplasmic Ca2+ are an early signal in the initiation of the apotosis process (Orrenius et al. 2003), through which irreversibly damaged cells or those that have lost their function in the organism are degraded in a controlled manner. The irreversible phase of this process begins with the expression of cytotoxic caspase-type proteases. Increased expression of these enzymes (caspases 3, 8, and 9) and the required transcription factors Bax and Fas was observed in neonatal rat cardiomyocytes during multi-day infrasound exposure (5 Hz, 130 dB) (Pei et al. 2011). At the same time, proteins that protect against apoptosis were downregulated.

Infrasound also leads to increased apoptosis in neuronal cells of the brain, as shown in the rat hippocampus (8 Hz, 110 dB; Zhang et al. 2016; Cai et al. 2014). From today's perspective, the hypothesis of Liu et al.

appears to be plausible. (2010, 2012) justified the idea that the additional outflow of calcium from mitochondria and endoplasmic reticulum into the cytosol caused by infrasound initiates the Ca2+-dependent apoptosis pathway and thus triggers long-term cytotoxic effects.

The evidence of a cytotoxic effect of infrasound has led to research into the medical application of infrasound for tumor therapy. One starting point was the observed inhibition of colorectal tumors in mice after a single exposure to infrasound (Zhang et al. 2013).

Interactions of infrasound with the cardiovascular system

Adverse effects of infrasound exposure have been described for various organs, including the liver and lungs (Nekhoroshev et al. 1991; Svigovyi and Glinchikov 1987), but the vast majority of data are available for the cardiovascular system. Harmful are 1982; Babisch 2011; Cai et al 2017, Millar and Steeels 1990; Søren sen et al. 2011). In the threshold range to infrasound, the regulatory function of the outer hair cells in the inner ear takes effect: Through their contraction (see below), these cells can transform an inaudible infrasound signal into an audible signal by lowering the hearing threshold. Consequently, the cardiovascular risks associated with audible noise sources must also be considered with regard to infrasound (Babisch et al. 2011; Cai et al. 2017).

Findings in Test Subjects

In an important pioneering study, the research group of Karpova et al. (1979) found reduced heart rate and arrhythmias in healthy 19- to 29-year-old subjects after exposure to infrasound (1–12 Hz, 110–132 dB). Using an older technique ("seismic cardiograph"), they observed a reduction in cardiac muscle strength, most pronounced at frequencies around 10 Hz. This reduction in heart rate was confirmed in 1980 by Wysocki et al. (e.g., at 8 Hz, 75 dB, and exposure times of up to 2 hours). Additionally, the authors demonstrated a reduction in peripheral vascular conductivity, skin temperature, and performance in choice response tasks. They hypothesized that the pressure fluctuations are detected via mechanoreceptors in the skin and lead to cerebrally triggered autonomic responses in the heart. In a more recent publication, the central finding was also recorded for low-frequency audible sound: Walker et al. (2016) found a 32% reduction in heart rate variability in healthy subjects.

Findings in Experimental Animals

Effects on the Intact Myocardium

Campbell et al. (1998) placed a small balloon in the left ventricle of rabbits and inflated and deflated it using low-frequency sound or infrasound. Vibrating the balloon in the heart resulted in a force reduction of approximately 10–20%. The authors believe that the cause of this effect is not the contraction process of the heart muscle, but rather a disruption of the preceding conduction pathway, which is linked to functional membrane structures.

Exposure of rats to infrasound (5 Hz, 130 dB) led to an increase in heart rate and blood pressure, while cardiac output decreased (Pei et al. 2007). Normally, contractile force increases with heart rate as an adaptation to increased oxygen demand (positive force-frequency relationship). The reduction in stroke volume suggests damage to this important regulatory mechanism, presumably diastolic dysfunction (Pei et al. 2009). At the morphological level (post-mortem examination), the authors observed changes in myocardial ultrastructure, including the sarcoplasmic reticulum, hemodynamic indices, and intracellular calcium concentrations. Alterations in L-type Ca2+ channels were also detected, with negative effects on

electromechanical coupling. In addition, platelet aggregation in the intercellular space was observed. The results confirm earlier findings by Gordeladze et al. (1986): after 3 hours of exposure to infrasound (8 Hz, 120 dB), swelling of the walls of both ventricles and punctate hemorrhages into the pericardium occurred. In the cardiomyocytes, increasing damage to the membranes of the sarcoplasmic reticulum and mitochondria was observed, as well as fragmentation of the myofibrils. In addition, changes in chromatin and other nuclear structures occurred. After discontinuing infrasound exposure, a substantial recovery occurred.

Microcirculation Disturbances

The changes induced by infrasound are similar to the stress effects of prolonged (multi-day) exposure to audible noise: The latter leads to an increase in blood pressure and cellular Ca2+ concentration in the vascular muscles, along with increased activation of neutrophil cells (Tiefenbacher et al. 2000; Millar et al. 1990; Altura et al. 1992). It is therefore not unreasonable to expect this activation to occur with infrasound as well. High neutrophil cell activity leads to a reduction in microcirculation in the surrounding tissue and thus to a reduced oxygen and substrate supply. This often results in uncontrolled death (necrosis) of undersupplied cells. Released cellular components trigger nonspecific inflammatory reactions, and in the longer term, destroyed cells are replaced by connective tissue (sclerosis or fibrosis). Such changes have been observed repeatedly in rats exposed to infrasound. Gordelaze et al. (1986) already observed severe microcirculatory disturbances, and Sharipova (2013) reported nonspecific inflammatory processes triggered by infrasound (13–30 Hz at 114 dB), followed by perivascular coronary sclerosis. These results have been confirmed by more recent studies even at lower sound pressures (90 dB and above; Lousinha et al. 2018).

On the generalizability of data from animal experiments

The previously published data and evidence presented for the effects of infrasound on cells, tissue, and organs derive largely from experiments on mammals. The sound pressure levels used (e.g., by Pei et al. 2009 and Gordeladze et al. 1986) are often higher than those expected under real-life conditions, such as in the vicinity of modern wind turbines. In some tests, they exceed the formal human pain threshold of 120 dB at 20 Hz. Such studies were mostly conducted on the effects of infrasound from high-emitting industrial facilities such as jet engines, motors, etc. Due to different analytical methods, a comparison of sound pressure levels is only possible to a limited extent. As will be shown later, it is not the absolute level of sound pressure that determines a biological effect, but rather the extent of short-term changes.

In addition, there are differences in sensitivity and adaptability between experimental animals and humans. As described above, for example, test subjects responded to infrasound with a reduction in heart rate, while rats responded with an increase. This indicates that the balance between parasympathetic and sympathetic modulation of heart rate is regulated differently in humans and rodents. Importantly, however, clear responses to infrasound exposure were measurable in all cited animal experiments.

Nevertheless, the observed damage to animal specimens, even at high infrasound pressures, provides valuable information on the susceptibility of underlying cell structures and organs to disruption. This facilitates the comparative identification of targets for elementary building blocks and signaling mechanisms, as they evolved from common precursors in mammalian evolution.

Resonance Phenomena

Resonance phenomena can be assumed for the cardiovascular system, including the lungs. This means that vibration of cell and tissue clusters due to the effects of airborne infrasound or corresponding structure-borne sound can be amplified in this way (Vinokur 2004). It has long been known that the upper human torso can develop resonances at frequencies between 5 and 250 Hz (Smith 2002; Randall et al. 1997). Most body

organs can now be assigned individual resonance frequencies, which often lie in the infrasound range (RKI 2007). This played an important role, for example, in the design of mechanical heart valves, as it is important to prevent organs of the human body from being set into resonant vibrations by the rhythm of the valve.

Interference between the fundamental vibration determined by the heartbeat and externally applied infrasound pulses has been little studied. The consequences of such interactions – attenuation and amplification – are worth considering because, for example, the pulses emitted by wind turbines (a three-blade turbine generates a fundamental vibration of 1 Hz at 20 rpm) are in the same frequency range as the human pulse (resting pulse of 60 = 1 Hz).

The Effect of Infrasound on the Hearing and Vestibular Systems

Perception in the Cochlea

In the inner ear, audible sound events are perceived in the cochlea's organ of Corti by locally causing the basilar membrane, which is filled with inner hair cells, to resonate. For most people, this occurs at frequencies above approximately 50 Hz. Slower, i.e., low-frequency vibrations, including infrasound, cannot produce a tonal auditory impression because the inner hair cells are surrounded by a fluid (endolymph), which dampens their movements. However, low-frequency audible sound and infrasound are capable of stimulating the outer hair cells, which protrude from the lymph fluid and are therefore more sensitive (Salt and Hullar 2010; Salt and Kaltenbach 2011).

It has long been known that stimulation of the outer hair cells leads to changes in their length. This process can be induced and observed experimentally in isolated hair cells of humans and various rodents (Brownell et al. 1985; Ashmore 2008). Since the outer hair cells are fused not only to the basilar membrane but also to the overlying tectorial membrane, the gap between the two membranes is reduced when these cells contract and increased when they expand. This leads to an increase or decrease in the sound pressure in the cochlea. Low-intensity external sounds are therefore perceived with increased sensitivity. The change in the length of the outer hair cells generates vibrations in the inner ear that can be measured for diagnostic purposes. This "otoacoustic emission" can be triggered by both low-frequency audible sound and infrasound. (Hensel et al. 2007). This makes the outer hair cells a target for the perception of infrasound, with a modulating effect on the hearing threshold. Their excitation may explain why sensitive individuals experience an increased perception of soft audible sounds when exposed to infrasound (Kaltenbach and Godfrey 2008).

Perception in the Vestibular System

The human vestibular system responds to vibrations and long-wave pressure oscillations whose frequencies lie below the range of tonal perception in the cochlea. This occurs in the inner ear in the saccule and utricle organs, which detect linear accelerations, including the effects of gravity, and in the semicircular canals, where rotational accelerations in all directions of space are registered. Signal conversion in these organs also occurs at hair cells, but with the help of the inertia of $CaCO_3$ crystals, the otoliths. These sensors are also activated by infrasound or low-frequency audible sound, as demonstrated in test subjects and mammals such as mice (Jones et al. 2010). They react with high sensitivity: the human vestibular system detects accelerations even below 1 thousandth of a g (Todd et al. 2008).

Elements of the vestibular system developed during the evolution of vertebrates (Fay and Popper 2000), with the principle of otolithic sensors being conserved. Otolith organs, which can detect low-frequency pressure

waves, are already present in fish, thus predating the development of the cochlea (Popper and Lu 2000). This provides infrasound access to a basic signaling system of all vertebrates.

During the perception of movement and balance control, the information coming from the vestibular apparatus is compared in the cerebrum with position signals from the eyes and stretch receptors in the body. This creates a precise perception in the brain, even of complex movements (Cullen 2019; Gu 2018). When the vestibular system is activated by infrasound, the accompanying information from the body's organs is missing, leading to a perceptual conflict. This conflict is similar to kinetosis, such as seasickness (Dooley and Morris 2014; Macefield and Walton 2015; Schomer and Erdreich 2015). Residents of wind turbines have repeatedly reported such attacks of dizziness; if such a perceptual conflict persists chronically, other symptoms such as severe sleep deprivation, tinnitus, and anxiety reactions also seem plausible.

The activation of distinct brain regions by infrasound

The compilation of potential sites of action of infrasound raises the question of how the resulting signals are reflected and processed in the brain. Modern imaging techniques such as functional magnetic resonance imaging (fMRI) enable the visualization of neuronal activity and connectivity in the brain, thus providing new insights into the perception of auditory and infrasound. The analytical method of "regional homogeneity" can reveal improved communication between neurons within a defined region. In a groundbreaking fMRI study, three regions were identified in the brains of test subjects that showed increased neuronal activity after exposure to infrasound (12 Hz) at intensities below the hearing threshold (Weichenberger et al. 2017; ➥Fig. 3). These regions are:

- a region near the auditory cortex (rSTG),
- the anterior cingulate cortex (ACC),
- the right amygdala (rAmyg).

Activation of these regions did not occur when infrasound was applied at an intensity above the individual's hearing threshold. Apparently, infrasound subconsciously alters the activity patterns in defined brain regions, i.e., in the absence of conscious perception. This signal transfer is presumably suppressed when audible sound pressures are perceived.

The regions activated by infrasound have been well studied with regard to their functions for the organism. While the rSTG region is indirectly involved in the processing of sound events, the ACC contains several centers of autonomic control, including those of respiratory rate and blood pressure (Critchley et al. 2003). Their activation has been demonstrated in certain contexts, for example, when engaging in a cognitively demanding task (Thomason et al. 2011). Recent studies suggest that a connection between unconscious perception and conscious recognition occurs in the ACC (Meneguzzo et al. 2014). The amaygdala is known for its involvement in the control of emotional reactions. fMRI studies attribute the role of a detector for the intensity of excitations (Bonnet et al. 2015).

The work of Weichenberger et al. (2017) provided the first concrete evidence suggests the involvement of specific brain areas in the perception of infrasound. This suggests an unconscious processing of infrasound-triggered signals in regulatory centers of the brain. Such signaling pathways could originate, among other things, from the outer hair cells (see above). It is known that these – unlike the inner hair cells – are also connected to nerve pathways that terminate in non-auditory centers of the brain (Weisz 2009). Other candidates include the otoliths of the vestibular system and the pressure receptors of the skin, such as the

Pacini corpuscle (sensitive in the range 10–300 Hz), the Merkel cell (0.3–3 Hz), and the Krause end bulb (3–40 Hz).

The presented data allow us to assume that the findings in respiratory rate and blood pressure recorded in patients after exposure to infrasound (e.g., from the vicinity of wind turbines) are caused by excitation of the ACC region. The anxiety also reported by residents suggests a possible involvement of the amygdala. However, since the infrasound used in the experiment differed from the characteristic infrasound pulses from wind turbines, no direct connection can be established between the changes in neuronal activity found in these test subjects and the findings in residents or patients. However, if one assumes that infrasound pulses from wind turbines (in the range of 1 to approximately 8 Hz) are received in the same or closely adjacent brain areas as the signals used in the test (12 Hz), this raises the suspicion of health risks from the subconscious perception of infrasound—and provides a starting point for further research.

Infrasound appears to have other, previously unknown effects during waking hours: Exposure to short episodes of a few seconds each led to the expected activation of the primary auditory cortex and tended to improve working memory (Weichenberger et al. 2015).

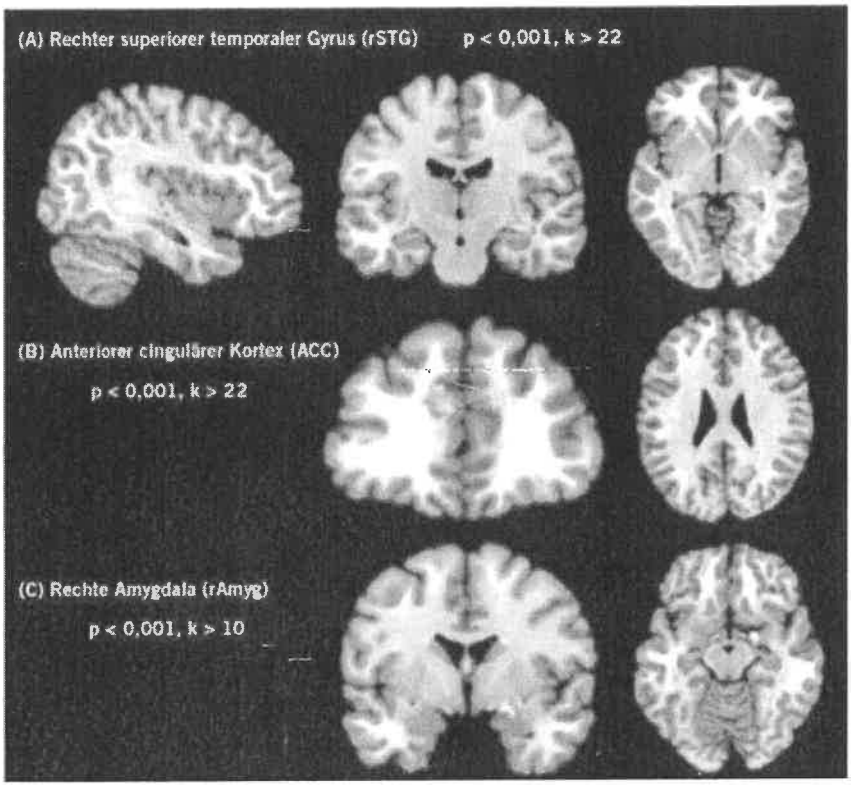


Fig. 3: fMRI maps of the brains of test subjects with areas of increased regional homogeneity (connectivity) during exposure to infrasound below the hearing threshold. The virtual slice planes are sagittal (left, only in A), frontal (middle), and transverse (right). Regions with differences compared to the control group (without sound exposure) are marked in color. 14 test subjects were treated with infrasound of 12 Hz sine for 200 s in a resting state. The intensity was set 2 dB below the (previously determined) individual hearing threshold. During this time, fMRI measurements were taken and then examined for areas of higher neuronal activity using regional homogeneity analysis (see above), compared to no sound exposure. The regions found are marked in color. The marked changes did not occur when the sound was exposed at the same frequency but at an intensity that the test subject could hear. This intensity was not perceived as painful (determined

individually in a preliminary test). Source: Weichenberger et al. 2017 Fig. 3: fMRI maps of the brain of test subjects with areas of higher regional homogeneity (connectivity) during exposure to infrasound below the hearing threshold level. The virtual planes are sagittal (left, A only), frontal (center) and transverse (right). Regions with differences to the control group (without sound exposure) are marked in color. 14 test subjects were treated in a state of rest with 12 Hz infrasonic waves for 200 s. The intensity was set 2 dB below their individual hearing threshold (as determined previously). fMRI measurements were taken during this time and the regional homogeneity analysis (see above) was then used to examine them for areas of higher neuronal activity in comparison with the absence of exposure to sound. The regions found during this process are marked in color. The marked changes did not occur during exposure to sound at the same frequency but at an intensity that was audible to the test subject. This intensity was not perceived as painful (individually ascertained in a preliminary trial). Source: Weichenberger et al. 2017
Fig. 3: fMRI maps of the brains of test subjects with areas of increased regional homogeneity (connectivity) during exposure to infrasound below the hearing threshold. The virtual cutting planes are sagittal (left, only in A), frontal (middle) and transverse (right). Regions with differences compared to the control group (without sound exposure) are highlighted in color. 14 subjects were treated with 12 Hz sine wave infrasound in a resting state for 200 s. The intensity was set 2 dB below the (previously determined) individual hearing threshold. During this time, fMRI measurements were taken and subsequently compared with Using regional homogeneity analysis (see above), areas of higher neuronal activity were examined, compared to no sound exposure. The regions identified are marked in color. The marked changes did not occur when the sound exposure occurred at the same frequency but with an intensity audible to the test subject. This intensity was not perceived as painful (determined individually in a preliminary test). Source: Weichenberger et al. 2017
Fig. 3: fMRI maps of the brain of test subjects with areas of higher regional homogeneity (connectivity) during exposure to infrasound below the hearing threshold level. The virtual planes are sagittal (left, A only), frontal (center), and transverse (right). Regions with differences from the control group (without sound exposure) are marked in color. 14 test subjects were treated in a state of rest with 12 Hz infrasonic waves for 200 s. The intensity was set 2 dB below their individual hearing threshold (as determined previously). fMRI measurements were taken during this time, and the regional homogeneity analysis (see above) was then used to examine them for areas of higher neuronal activity in comparison with the absence of exposure to sound. The regions found during this process are marked in color. The marked changes did not occur during exposure to sound at the same frequency but at an intensity that was audible to the test subject. This intensity was not perceived as painful (individually ascertained in a preliminary trial). Source: Weichenberger et al. 2017

Conclusion and Conclusions

Points of Attack for Infrasound

The available scientific data indicate that infrasound is assessed as a stressor in humans as well as in mammals (test animals). The organism responds with adaptive and defensive reactions, the basic elements of which are also known for other stressors. The effects known today include:

- direct damage to cells and organs and
- disruption of signaling chains whose information is evaluated in the brain.

Targets for the damaging effects of infrasound have been found at all levels of the mammalian organism.

- At the cellular level, disruption of membrane processes has been demonstrated. This not only impairs the function of individual cells, but also their interactions within tissue, such as microcirculation, muscle contraction, or neuronal signal transmission. Corresponding evidence comes almost exclusively from animal experiments. The high degree of similarity between the subcellular mechanisms conserved in mammalian evolution makes similar damage likely in human cells as well.

- The cardiovascular system reacts to infrasound on two levels: Disruptions to the membrane processes required for contraction and microcirculation in the myocardial tissue occur, resulting in reduced blood flow and efficiency of the heart muscle. In addition, there is the centrally coordinated stress defense (see above), which causes a drop in heart rate with rising blood pressure and reduced cardiac output. The result is the appearance of incipient heart failure.

- Infrasound acts as a disruptive signal on the signaling systems in the inner ear, especially the vestibular system and outer hair cells, and is not coordinated with the control and compensatory mechanisms that typically accompany physical movements (such as visual perception and the pressure receptors of muscles and other organs). This results in a clinical picture similar to kinetosis.

- In the brain, infrasound is perceived in defined areas that are involved in the control of autonomic functions (including respiratory rate and blood pressure) and emotional control. The activation of these areas occurs without conscious perception. This may explain why exposure to infrasound during sleep leads to a variety of stress-like symptoms. It is still unclear which specific peripheral receptors and signaling pathways provide the information for the activation of these brain areas.

Wind turbines: real dangers and study subjects

There are obvious connections between the results presented here on test subjects or laboratory animals and the frequently reported real illnesses that occur in the vicinity of infrasound generators, but often no complete causal chain. This is especially true for wind turbines, the number of which has increased dramatically in recent years. Based on their own diagnoses, general practitioners estimate a minimum of approximately 180,000 people affected in the vicinity of these turbines (Kaula 2019). At the same time, several epidemiological studies have been published in recent years that essentially find no negative effects of the infrasound emitted by wind turbines on residents. There are clear reasons for these discrepancies.

Studies with test subjects lack Often relevant to health risk factors

Current studies commissioned by governments and planning authorities reveal significant limitations of experimental or statistical approaches in the critical frequency range. For example, known, potentially harmful parameters of the infrasound emitted by wind turbines are excluded from application or analysis:

- Epidemiological studies from Denmark (Poulsen et al., several publications in 2018 and 2019) found no statistical correlation between sound emissions from wind turbines and certain diseases (cardiovascular damage, diabetes, hypertension, and miscarriages) among residents. The collected health data were compared with the sound pressure levels measured at the respective locations. These reference points were measured according to the so-called A-weighting, i.e., in the range above 20 Hz. The infrasound from the wind turbines (and thus also the peaks between 1 and 8 Hz, see Fig. 1) was therefore generally not recorded, and the health risks it may have caused were therefore not part of the analysis.

- A scientific consortium commissioned by the Finnish government concluded that the infrasound emitted by wind turbines was not the cause of the health problems reported by residents of several wind farms within a radius of approximately 2.5 km (Maijala et al. 2020). In this study, infrasound frequencies below 8 Hz were also recorded, but in the form of third-octave spectra. The latter consist of average sound pressure values over defined frequency ranges, each with a third-octave range. By averaging, the steep sound pressure peaks emanating from wind turbines, which occur at characteristic frequencies dependent on speed (see Fig. 1), have only a minor impact on the measurement result. This "smoothed out" the signature most likely responsible for health impairments. As expected, residents did not exhibit any significant complaints, even when exposed to the recorded sound for a few minutes in a blind test.

- An experimental study was conducted in Germany on behalf of the Federal Environment Agency (UBA 2020) in which test subjects were exposed to infrasound (3–18 Hz) in the form of sine waves. This "pure"—i.e., artificially produced and simplified—infrasound, according to the authors, rarely occurs in practice, so no conclusions can be drawn about the effects of infrasound from real sources, such as the pulsating emissions of wind turbines. Nevertheless, all test subjects found the sinusoidal infrasound, which was only exposed for 30 minutes, to be bothersome in a blind test, without this being reflected in physiological data (blood pressure, pulse, EEG).

This last case also provides an example of the limited validity of studies that use narrowly defined exposure times. As a result, effects that actually occur with longer or chronic exposure remain undetected. A harmful agent develops a pathophysiological effect many times greater with chronic exposure than with short-term exposure. Adaptive responses are usually only successful if sufficient recovery periods are provided. Therefore, chronic exposure to infrasound during sleep is considered particularly problematic.

The particular health risk of infrasound emitted by wind turbines

Since the vast majority of data from people exposed to infrasound is available for wind turbines, they have become a suitable study object for investigating the effects of infrasound from modern sources (overview in Roos 2019).

The starting point is known complaints from residents, which have been increasingly voiced in recent years. Starting with the primary symptom of severe sleep disturbance, dizziness, anxiety, reduced respiratory rate, depression, and hypertension develop (Kaula 2019; Stelling 2015). One consequence of sleep deprivation is an increase in the stress hormone cortisol (Minkel et al. 2014). Due to the low specificity of individual symptoms and individual differences in sensitivity, infrasound from wind turbines is often not readily identifiable as the cause (e.g., Kamp and Berg 2018), so that an estimate of the prevalence (see above) is likely too low.

Comparative studies, for example, between rotating and switched-off turbines or between exposed and non-exposed residences, have led to the conclusion that rapid changes in sound pressure represent the actual hazard potential, rather than its absolute values. While pulse-free infrasound noise (from natural sources or the background after switching off emitting systems) is not annoying, fluctuating, abrupt pressure changes are very likely to trigger the complaints of residents mentioned above.

(Stelling 2015; Dooley and Metelka 2014; Palmer 2017). Therefore, when assessing a health hazard, the often considerable sound pressure caused by the wind itself (which is measurable when the turbine is stationary) must be distinguished from the pulsatile emissions of the rotating turbine (see caption Fig. 1).

The illnesses reported by residents of wind turbines indicate physical damage and reactions that occur in dangerous proximity to the aforementioned, experimentally determined effects of infrasound:

- Dizziness and the impression of kinetosis (seasickness or motion sickness) can be explained by irritation of the otolith cells of the vestibular system.
- Severe sleep deprivation and the stress effects on autonomic functions (increased blood pressure, respiratory depression) and emotional control (anxiety, depression, irritability) are compatible with the activation of distinct brain areas in the subconscious.
- The frequently reported cardiovascular problems are very likely caused by the aforementioned stress reactions. The experimentally observed reduction in the contractile force of the heart muscle should be considered as a further risk factor, even if evidence in patients is still pending.

Need for Research and Regulation

From a medical perspective, the aforementioned targets and effects on various biological systems constitute a substantial health risk for individuals exposed to infrasound. Nevertheless, obvious causal relationships are partly incomplete and can only be concluded through further research. However, it would be negligent to interpret the ongoing lack of suitable research as an indication of a low or nonexistent risk potential of infrasound from wind turbines, as is unfortunately often the case (LUBW 2016; UBA 2016, 2020). The overall picture of currently established knowledge – including the still incomplete data – justifies concerns about serious health risks. One of the principles of preventive medicine is to identify and address health threats as they arise, before negative effects escalate.

Urgent research goals include:

- the effects of real emissions from infrasound sources on test subjects and laboratory animals, including the potential danger of steep pressure pulses from wind turbines;
- the creation of quantifiable cause-and-effect relationships, i.e., sound-pressure-effect curves for key criteria such as sleep quality, blood pressure, activation of specific brain areas, etc.

In addition to infrasound, which can be measured several kilometers away, wind turbines also emit emissions at close range (a few hundred meters), primarily audible sound and the shadow cast by rotor blades. These stress factors are known to also lead to psychological and physical reactions in residents. The question of the extent to which these infrasound-induced reactions are amplified or modified remains unanswered.

As long as the potentially negative effects of wind turbines on humans cannot be quantified, the safety distance from residential areas of 10 times the height of the turbine, which is applicable in Bavaria, is a reasonable lower limit for planning. The decline of the main symptom of "severe sleep disturbance" with distance from wind turbines has been documented for years (Paller 2016). Occasional statements that the noise from a wind turbine and the nuisance to residents do not depend significantly on distance (e.g., Baumgart 2020) are not substantiated.

A prerequisite for a proper assessment of the health risk is the acquisition of sufficient data. To date, this has been hampered by the measurement regulations of the TA Lärm (Technical Instructions on Noise), which exclude the particularly critical range between 1 and 8 Hz. In the upcoming revision, measurements in this frequency range should be made mandatory.

The assessment of infrasound effects must be carried out independently of the human hearing or perception threshold. The latter are defined as sound levels that 50% or 90% of people can no longer hear, respectively, and reflect the sensitivity of perception in the cochlea. As shown here, infrasound-induced damage and stress responses occur via fundamentally different structures and mechanisms. The fact that infrasound emissions from wind turbines are usually well below the human perception threshold does not make them any less problematic, partly due to the high sensitivity of the vestibular system (see above).

In the discussion about the acceptance of wind turbines, it is occasionally claimed that the stress reactions of some residents are based on a nocebo effect, i.e., a negative expectation (bias) towards wind turbines, rather than on the physical effects of sound exposure (Farboud et al. 2013; Crichton et al. 2014, 2015). These statements are based on evidence from Test subjects who experience greater annoyance from wind turbines when their expectations are negative (asked or experimentally provoked) than when their attitudes are positive. Psychogenic changes may play a role in residents' exposure to wind turbines, which are also visually intrusive, and modify physical damage. They do not explain the illnesses or risks emanating from objectively identified points of attack in the vestibular system, brain, and heart of test subjects and laboratory animals. Stress and avoidance reactions of wild animals to wind turbines (Agnew et al. 2016; Lopucki et al. 2018) also contradict this assumption. As long as no dose (energy)-response curves are available for experimentally documented effects and the illnesses reported by residents, it is too early to determine the extent of the nocebo effect.

Finally, it should be remembered that a stressor that can be controlled briefly can become highly dangerous through repeated application: A drop of water falling on a person's forehead is a trivial matter in itself. However, if a drop of water falls on a person's forehead every 30 seconds, it can be considered a form of torture.

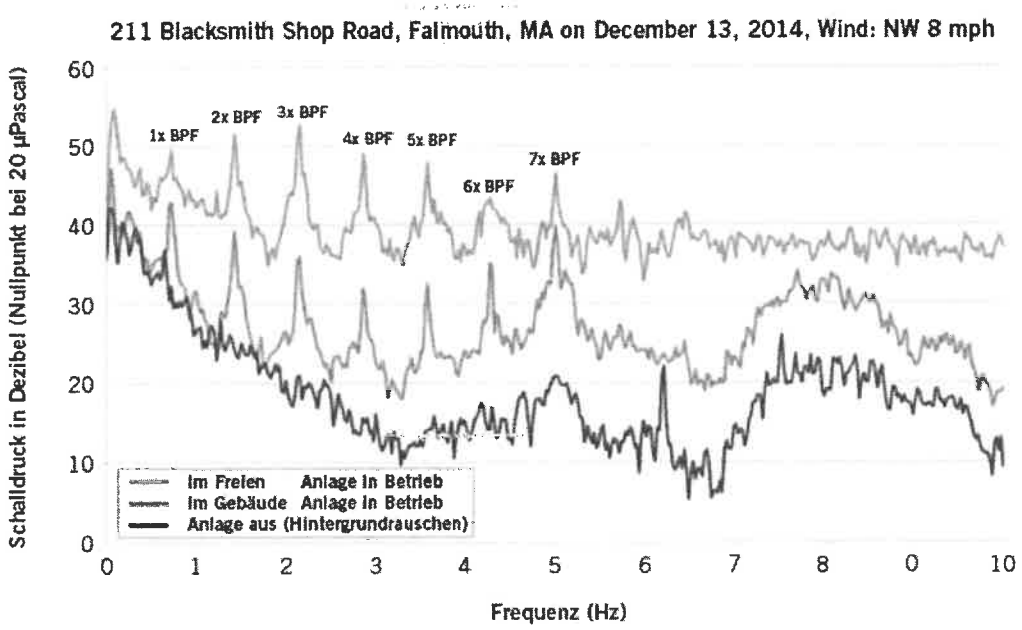


Fig. 1: Frequency pattern of infrasound from two wind turbines. Green line: outside the building. The fundamental rotation frequency at approximately 0.7 Hz (1x BPF) and six harmonic peaks (2x BPF ... 7x BPF) are visible. Red line: Inside the building, the total sound pressure is significantly lower, but the frequency and amplitude of the infrasound peaks mentioned remain unchanged. The sound pressure caused by the wind itself is reduced inside the building, but not the pulses emitted by the turbine. Black line: background noise when the turbine is switched off. Wind turbines: Vestas, 1.65 MW, distances 421 m and 792 m. BPF: blade pass

frequency (frequency of blade passage on the mast). Source: M. Bahtiarian, A. Beaudry, Noise Control Engineering, Billerica, USA 2015

Acknowledgements: The authors thank Dr. L. Ascone and Prof. Dr. S. Kühn, University Medical Center Hamburg-Eppendorf, Department of Psychiatry and Psychotherapy, for their critical review of the manuscript.

Conflict of interest: Both authors declare that they have no conflicts of interest.

References

Agnew RCN, Smith VJ, Fowkes RC: Wind turbines cause chronic stress in badgers (Meles meles) in Great Britain. J Wildlife Dis 2016; 52: 459–467.
Altura BM, Altura BT, Gebrewold A et al.: Noise-induced hypertension and magnesium in rats: relationship to microcirculation and calcium. J Appl Physiol 1992; 72: 194-202.
Andren L, Lindstedt G, Björkman M et al.: Effect of noise on blood pressure and "stress" hormones. Clin Sci 1982; 62: 137–141.
Ashmore J: Cochlear outer hair cell motility. Physiol Rev 2008; 88: 173–210.
Babisch W: Cardiovascular effects of noise. Noise Health 2011; 13:201–204.
Bahtiarian M, Beaudry A: Infrasound measurements of Falmouth Wind Turbines, Technical Memo 2015 - 004. Noise Control Engineering, Billerica, MA 01821, USA.
Baumgart J: From Flow to Pressure – Noise from Wind Turbines.
Acoustic J 2020; 2: 23–40.
Bonnet L, Comte A, Tatu L et al: The role of the amygdala in the perception of positive emotions: an "intensity detector"". Front Behavior Neurosci, 2015; 9.
Brownell WE, Bader CR, Bertrand D et al.: Evoked mechanical responses of isolated cochlear outer hair cells. Science 1985; 227: 194-196.
Cai J, Jing D, Shi M et al.: Epigallocatechin gallate (EGCG) attenuates infrasound-induced neuronal impairment by inhibiting microglia-mediated inflammation. J Nutr Biochem 2014; 25: 716–772.
Cai Y, Hansell AL, Blangiardo M et al.: Long-term exposure to road traffic noise, ambient air pollution, and cardiovascular risk factors in the HUNT and lifelines cohorts. Eur Heart J 2017; 38: 2290–2296.
Campbell K, Wu Y, Kirkpatrick D, Slinker BK: Myocardial contractile depression from high frequency vibration is not due to increased cross-bred fracture. Am J Physiol 1998; 274: H1141–H1151.
Chaban R, Ghazy A, Georgiade E, Stumpf N, Vahl CF: Negative effect of high level infrasound on human myocardial contractility: in vitro controlled experiment. Noise and Health, online 2020 (NAH_28:19R4_OA DOI: 10.4103/nah.NAH_28_19).
Crichton F, Chapman S, Cundy T, Petrie K: The link between health complaints and wind turbines: support for the nocebo expectations hypothesis. Frontiers Public Health 2014; 2:220.
Crichton F, Dodd G, Schmid B et al.: Framing sound: Using expectations to reduce environmental noise annoyance. Environment Res 2015; 142: 609-614.
Critchley HD, Mathias CJ, Josephs O et al.: Human cingulate cortex and autonomic control: converging neuroimaging and clinical evidence. Brain 2003; 126: 2139–2152.
Cullen K: Vestibular processing during natural self-motion: implications for perception and action. Nature Rev 2019; 20:347–439.
Dooley KA, Metelka A: Acoustic interaction as a primary cause of infrasonic spinning mode generation and propagation from wind turbines. Proceedings of Meetings on Acoustics 2014; 20: 040002. Acoustical Society of America.
Dooley KA, Morris EA: Systems and methods for control of motion sickness within a moving structure due to infrasound pressures. U.S. Patent Application 2014; 14/478,468.
Farboud A, Crunkhorn R, Trinidade A: Wind turbine syndrome: fact or fiction?

J Laryngol Otol 2013; 127: 222–226.
Fay RR, Popper AN: Evolution of hearing in vertebrates: the inner ears and processing. Hearing Res 2000; 149, 1-10.
Gordeladze AS, Glinchikov VV, Usenko VR: [Experimental myocardial ischemia caused by infrasound]. Gig Tr Prof Zabol 1986; 6:30–33.
Gu Y: Vestibular signals in pRimate cortex for self-motion perception. Curr Opin Neurobiol 2018; 52:10–19.
Hensel J et al.: Impact of infrasound on the human cochlea. Hearing Res 2007; 233: 67-76.
Jones GP et al.: The vestibular system mediates sensation of low-frequency sounds in mice. J Assoc Res Otolaryngol 2010; 11:725–732.
Kaltenbach JA, Godfrey DA: Dorsal cochlear nucleus hyperactivity and tinnitus: are they related? Am J Audiol 2008; 17: 148–161
Kamp I von, Berg F v.d.: Health effects related to wind turbine sound, including low-frequency sound and infrasound. Acoust Aust 2018; 46:31–57.
Karpova NI, Alekseev SV, Erokhin VN et al.: [Early body reaction to low-frequency acoustic oscillations]. Gig Tr Prof Zabol 1979; 10: 16–19.
Kaula S: Study on the health effects of residents caused by the operation of wind turbines in Germany based on case studies. German Association for the Protection of Sound for Humans and Animals. 2019;
Personal communication from the author (pre-publication, https://www.dsgs.info/INFO/Aktuelles/ and https://windveto.org/NEWS/Studie/).
Liu Z, Gong L, Li X et al.: Infrasound increases intracellular calcium concentration and induces apoptosis in hippocampi of adult rats. Mol Med Reports 2012; 5: 73–77.
Liu J, Lin T, Yan X, Jiang W, Shi M, Ye R, Rao Z, Zhao G: Effects of infrasound on cell proliferation in the dentate gyrus of adult rats. Neuroreport 2010; 21: 585–589.
Lopucki R, Klich D, Ščibior A et al.: Living in habitats affected by wind turbines may result in an increase in corticosterone levels in ground-dwelling animals. Ecological Indicators, 2018; 84: 165–171.
Lousinha A, Oliveira MJ, Borrecho G et al.: Infrasound induces coronary perivascular fibrosis in rats. Cardiovasc Pathol 2018; 37: 39–44.
LUBW: State Institute for Measurements, Biology and Environmental Protection Baden-Württemberg: Low-frequency noise including infrasound from wind turbines and other sources. February 2016 (https://pudi.lubw.de/detailseite/-/publication/84558).
Maijala P, Turunen A, Ilmari K et al.: Infrasound does not explain symptoms related to wind turbines. Publications of the Government's analysis, assessment and research activities, PrimeMinister's Office, Helsinki 2020, p. 34.
Macefield VG, Walton DK: Susceptibility to motion sickness is not increased following spinal cord injury. J Vestib Res 2015; 25:35–39.
Meneguzzo P, Tsakiris M, Schioth HB et al.: Subliminal versus supraliminal stimulate activate neural responses in anterior cingulate cortex, fusiform gyrus and insula: a meta-analysis of fMRI studies. BMC Psychol 2014; 2:52–63.
Michaud DS, Feder K, Keith SE et al.: Exposure to wind turbine noise: Perceptual responses and reported health effects, J Acoust Soc Am 2016; 139: 1443–1454.
Millar K, Steels MJ: Sustained peripheral vasoconstriction while working in continuous intense noise. Aviat Space Environ Med 1990; 61: 695-698.
Minkel J, Moreta M, Muto J et al.: Sleep deprivation potentiates HPA axis stress reactivity in healthy adults. Health Psychol 2014; 33: 1430–1434.
Nekhoroshev AS, Glinchikov VV. [Reaction of hepatocytes to infrasound exposure]. Gigiena i Sanitariia 1991; 2:45–47.
Orrenius S, Zhivotovsky B, Nicotera P: Regulation of cell death: the calcium–apoptosis link. Nature Rev Mol Cell Biol 2003; 4:552–556.

Paller C: Exploring the association between proximity to industrial wind turbines and self-reported health outcomes in Ontario, Canada. MSc Thesis Univ. Waterloo, 2014.
Palmer WKG: Why wind turbine sounds are annoying, and why it matters. Global Environmental Health Safety 2017; 1:12-17.
Pei Z, Sang H, Li R et al.: Infrasound-induced hemodynamics, ultrastructure, and molecular changes in the rat myocardium. Environ Toxicol 2007; 2: 169–175.
Pei Z, Zhuang Z, Xiao P et al.: Influence of infrasound exposure on the whole L-type calcium currents in rat ventricular myocytes. Cardiovasc Toxicol 2009; 9:70–77.
Pei Z, Chen BY, Tie R et al.: Infrasound exposure induces apoptosis of rat cardiac myocytes by regulating the expression of apoptosis-related proteins. Cardiovasc Toxicol 2011; 4:341–346.
Pei Z, Meng R, Zhuang Z et al.: Cardiac peroxisome proliferator-activated receptor-gamma-expression is modulated by oxidative stress in acutely infrasound-exposed cardiomyocytes. Cardiovasc Toxicol 2013; 4:307–315.
Pilger Ch, Ceranna L: The influence of periodic wind turbine noise on infrasound array measurements. J Sound Vibr 2017; 88: 188-200.
Popper AN, Lu Z: Structure-function relationships in fish otolith organs. Fish Res 2000; 46:15-25.
Poulsen AH, Raaschou-Nielsen O, Peña A et al.: Long-term exposure to wind turbine noise and redemption of anti-hypertensive medication: a nationwide cohort study. Environ Int 2018; 121 (Pt1): 207–215.
Poulsen AH, Raaschou-Nielsen O, Peña A et al.: Long-term exposure to wind turbine noise and risk for myocardial infarction and stroke: a nationwide cohort study. Environmental Health Perspective 2019; 2019: 037004-1-10 (and subsequent publications in the journal).
Poulsen AH, RAaschou-Nielsen O, Peña A et al.: Impact of long-term exposure to wind turbine noise on redemption of sleep medication and antidepressants: a nationwide cohort study. Environ Health Perspect 2019; 127: 037005-1-9.
Qiu P, Zhang Z, Jiang Y et al.: Effect of infrasound on ultrastructure and permeability of rat's blood-retinal barrier. Chin J Ophthalmol 2002; 38: 499–501.
Robert Koch Institute (RKI): Infrasound and low-frequency sound – a topic for environmental health protection in Germany? Gesundheitsschutz 2007; 50: 1582.
Roos W: Infrasound from wind turbines – a neglected health problem. Naturwiss Rdschau 2019; 72: 343–350.
Randall JM, Matthews RT, Stiles MA: Resonant frequencies of standing humans. Ergonomics 1997; 40: 879–886.
Salt AN, Hullar TE: Responses of the ear to low frequency sounds, infrasound and wind turbines. Hearing Res 2010: 268: 12-21.
Salt AN, Kaltenbach JA: Infrasound from wind turbines could affect humans. Bull Sci Technol Soc 2011; 31: 296–302.
Schomer PD, Erdreich J: A theory to explain some physiological effects of the infrasonic emissions at some wind farm sites. J Acoust Soc Am 2015: 137: 1356-1365
Sharipova S: Osmotic resistance of blood erythrocytes at rats uncover in vitro infrasonic waves action. Internat J Biol Chem 2013; 5:18-23.
Smith SD: Characterizing the effects of airborne vibration on human body vibration response. Aviat Space Environ Med 2002; 73:36–45.
Sørensen M, Hvidberg M, Hoffmann B et al.: Exposure to road traffic and railway noise and associations with blood pressure and self-reported hypertension: A cohort study. Environ Health 2011; 10:92.
Stelling K: Infrasound / low frequency noise and industrial wind turbines. Information report, Multi-municipal wind turbine working group, 2–46, 2015 (https://www.wind-watch.org/documents/infrasoundlow-frequency-noise-and-...).
Svigovyi VI, Glinchikov VV: [Effect of infrasound on pulmonary structure]. Gig Tr Prof Zabol 1987; 34-37.

Tiefenbacher CP, Bleeke T, Vahl C et al. : Endothelial dysfunction of coronary resistance arteries is improved by tetrahydrobiopterin in atherosclerosis; Circulation 2000; 102: 2172-2179.
Todd NP, Rosengren SM, Colebatch JG: Tuning and sensitivity of the human vestibular system to low-frequency vibration. Neurosci Lett 2008; 444: 36-41.
Thomason ME, Hamilton JP, Gotlib IH: Stress-induced activation of the HPA axis predicts connectivity between subgenual cingulate and salience networks during rest in adolescents. Child Psychol Psychiatry 2011; 52: 1026-1034.
UBA, Federal Environment Agency: Possible health effects of wind turbines. Position November 2016 (https://www.umweltbundesamt.de/sites/default/files/medien/1968/publikat...).
UBA, Federal Environment Agency: Noise effects of infrasound emissions, texts 163/2020.
Vinokur R: Infrasonic sound pressure in dwellings at the Helmholtz resonance actuated by environmental noise and vibration. Applied Acoustics 2004; 65: 143–151.
Walker ED, Brammer A, Cherniack MG, Laden F, Cavallari JM: Cardiovascular and stress responses to short-term noise exposures - A panel study in healthy males. Environ Res 2016; 150: 391–397.
Weichenberger M, Bauer M, Kühler R et al.: Altered cortical and subcortical connectivity due to infrasound administered near the hearing threshold – Evidence from fMRI. PLOS one 2017; 12: e01744201.
Weichenberger M, Kühler R, Bauer M et al.: Brief bursts of infrasound may improve cognitive function. An fMRI study. Hearing Res 2015; 328: 87–93.
Weisz C et al. The postsynaptic function of type II cochlear afferents. Nature 2009; 461: 1126–1129.
Wysocki K, Schultz K, Wieg P: Experimental studies on the influence of infrasound pressure on humans. Z Ges Hyg 1980; 26: 436–440.
Zhang MY, Chen C, Xie XJ et al.: Damage to the hippocampus of rats after being exposed to infrasound. Biomed Environ Sci 2016; 29: 435–442.
Zhang H, Qi P, Si SY, Ma WM: Effect of infrasound on the growth of colorectal carcinoma in mice. Chin J Cancer Prevent Treatm 2013; 20: 1145–1149.
Contact

Prof. Dr. Werner Roos (em.)
Graf-Heinrich-Straße 2
79822 Titisee-Neustadt
werner.roos@pharmazie.uni-halle.de

Prof. Dr. Christian Vahl (em.)
University Medical Center Mainz
Langenbeckstraße 1, Building 102
55131 Mainz
christian.vahl@unimedizin-mainz.de

Corroborating Sources for a Study from the German Publication ASU (Arbeitsmedizin/Sozialmedizin/Umweltmedizin)

ASU / Journal for Medical Prevention, published in issue 07-2021
Study conducted by Prof. Dr. Emeritus W. Roos and Prof. Dr. Emeritus C. Vahl

Link to German language website with article: https://www.asu-arbeitsmedizin.com/wissenschaft/wissenschaftliche-grundlagen-fuer-eine-bewertung-gesundheitlicher-risiken-infraschall
German to English translation of study: https://www-asu--arbeitsmedizin-com.translate.goog/wissenschaft/wissenschaftliche-grundlagen-fuer-eine-bewertung-gesundheitlicher-risiken-infraschall?_x_tr_sl=de&_x_tr_tl=en&_x_tr_hl=en&_x_tr_pto=wapp

This research paper confirms the health risks from wind turbines from multiple studies going back to 2009, as well as later ones published up through 2025.

1) See pages pages 3-6 of Drs. Roos and Vahl study, which are validated by Dr. Ursula Bellut-Staeck's 2025 study entitled: ***A fundamental basis for all living creatures, mechanotransduction, is significantly endangered by periodic exposure to impulsive infrasound and vibration from technical emitters - in particular cardiovascular and embryological functions***. Here is the link to Dr. Bellut-Staeck's study: https://www.scirea.org/journal/PaperInformation?PaperID=12440

2) See pages pages 5-6 and 10-11 of Drs. Roos and Vahl study, which are validated by W. Ben Johnson MD in his testimony in the two following articles: a) MasterResource Blog: ***Health Effects of Wind Turbines: Testimony of Ben Johnson versus MidAmerican Energy (Madison County, Iowa),*** August 2019. Link to this article: https://www.masterresource.org/wind-turbine-noise-issues/health-effects-of-wind-turbines-testimony-of-ben-johnson-versus-mid-american-energy-project-in-madison-country-iowa/, b) Dr. Ben Johnson's presentation before the Kansas State Legislature in Feb 2022, entitled ***Assessing Adverse Health Effects (Confirmed and Potential) from Industrial Wind Turbine Noise Immissions***:
https://www.kslegislature.gov/li_2022/b2021_22/committees/ctte_s_utils_1/documents/testimony/20220207_01.pdf

3) See pages 5-6 of Drs. Roos and Vahl study, which are validated by Prof Jerry L Punch and Prof Richard R James study in 2016 entitled: ***Wind Turbine Noise and Human Health: A Four-Decade History of Evidence that Wind Turbines Pose Risks***, see link at https://hearinghealthmatters.org/wp-content/uploads/2023/03/16-10-21-Wind-Turbine-Noise-Post-Publication-Manuscript-HHTM-Punch-James.pdf Also see Prof Jerry L Punch's Feb 2022 presentation before the Kansas Senate and Utilities Committee entitled ***Effects of Wind Turbine Noise on Human Health:***
https://www.kslegislature.gov/li_2022/b2021_22/committees/ctte_s_utils_1/documents/testimony/20220208_02.pdf

4) See pages 7-8, 11-14 of Drs. Roos and Vahl Study, which are validated by Dr. Nina Pierpont's 2009 study entitled ***Wind Turbine Study*** and Prof Calvin Luther Martin's 2010 report entitled ***Your Guide to Wind Turbine Syndrome...a roadmap to this complicated subject***. PDFs of both have been submitted to Whitman County Planning Commission and the County Attorney Denis Tracy.

Megan Zumbuhl Health Effects - general

From: Denis Tracy
Sent: Tuesday, December 16, 2025 10:22 AM
To: Megan Zumbuhl
Subject: FW: For the Public Record for the Public Hearing
Attachments: Long-term quantification and characterisatio of wind farm noise amplitude modulation-Science Direct 2021.pdf; Human Health, Rights and Wind Turbine Deployment in Canada-Journal of Social Sciences 2017.pdf; Adverse Health Effects of Industrial Wind Turbines.pdf; Health Effects of Wind Turbines-Ben Johnson Testimony.pdf

From: Julie Clarkson <jclark766@hotmail.com>
Sent: Tuesday, December 16, 2025 10:02 AM
To: Denis Tracy <DenisT@whitmancounty.gov>
Subject: Fw: For the Public Record for the Public Hearing

Sent from Outlook

From: Julie Clarkson <jclark766@hotmail.com>
Sent: Sunday, December 14, 2025 10:18 PM
To: alan.thomson@whitmancounty.gov <alan.thomson@whitmancounty.gov>; grace.dibiase@whitmancounty.gov <grace.dibiase@whitmancounty.gov>; commissioners@whitmancounty.gov <commissioners@whitmancounty.gov>; denist@whitmancounty.org <denist@whitmancounty.org>
Subject: For the Public Record for the Public Hearing

Adding for the record that none of these studies were added to the Planning Division website.
Julie

From: Julie Clarkson <jclark766@hotmail.com>
Sent: Wednesday, June 4, 2025 4:44 PM
To: alan.thomson@whitmancounty.gov <alan.thomson@whitmancounty.gov>; grace.dibiase@whitmancounty.gov <grace.dibiase@whitmancounty.gov>
Cc: Julie <jclark766@hotmail.com>
Subject: Wind Turbine Studies and Documentation

June 4, 2025

Whitman County Commissioners

I-26

Whitman County Planning Commission
Whitman County Planner

Dear Commissioners, Planning Commission members and County Planner:

In an effort to promote transparency regarding the impacts of large wind turbines, I respectfully request that the following studies and documents be added to the Whitman County Planning Division website.

Human Health, Rights and Wind Turbine Deployment in Canada – Journal of Social Sciences 2017

https://file.scirp.org/pdf/JSS_2017051714591773.pdf

Abstract: Canada has ratified international conventions which recognize the individual's right to the enjoyment of the highest attainable standard of health. Despite the adoption of these covenants governments sometimes support policies and practices which trade off individual human health with other conflicting interests. This review evaluates the individual's right to health against government policies and practices which support wind energy deployment in Canada. Our analysis presents government documents, peer reviewed literature, and other references which support the conclusion that wind energy deployment in Canada can be expected to result in avoidable harm to human health. This harm conflicts with contemporary health and social justice principles. Governments have a responsibility to help Canadians maintain and improve their health by generating effective responses for the prevention of avoidable harm. Individuals have a right to make informed decisions about their health. Knowledge gaps and potential risks to health should be fully disclosed. Individuals should not be exposed to industrial wind turbines without their informed consent.

Adverse health effects of industrial wind turbines

https://pmc.ncbi.nlm.nih.gov/articles/PMC3653647/

Abstract: Canadian family physicians can expect to see increasing numbers of rural patients reporting adverse effects from exposure to industrial wind turbines (IWTs). People who live or work in close proximity to IWTs have experienced symptoms that include decreased quality of life, annoyance, stress, sleep disturbance, headache, anxiety, depression, and cognitive dysfunction. Some have also felt anger, grief, or a sense of injustice. Suggested causes of symptoms include a combination of wind turbine noise, infrasound, dirty electricity, ground current, and shadow flicker.1 Family physicians should be aware that patients reporting adverse effects from IWTs might experience symptoms that are intense and pervasive and might feel further victimized by a lack of caregiver understanding.

Health Effects of Wind Turbines: Testimony of Ben Johnson versus MidAmerican Energy (Madison County, Iowa)

https://www.masterresource.org/wind-turbine-noise-issues/health-effects-of-wind-turbines-testimony-of-ben-johnson-versus-mid-american-energy-project-in-madison-country-iowa/

"The annoyance of sight and the heard pulsating wind turbulence creates indirect adverse health effects. This combined with the direct effects of sleep disturbance may activate the body's autonomic nervous system to increase sympathetic-mediated responses with endocrinological consequences."

"Increasingly activated, risk factors that promote adverse cardiovascular consequences may then promote/facilitate/enhance cardiovascular disease – most easily named as hypertension, arteriosclerosis, ischemic heart disease and stroke."

Long-term quantification and characterization of wind farm noise amplitude modulation

https://www.sciencedirect.com/science/article/abs/pii/S0263224121006400?via%3Dihub

The large-scale expansion of wind farms has prompted community debate regarding adverse impacts of wind farm noise (WFN). One of the most annoying and potentially sleep disturbing components of WFN is amplitude modulation (AM). Here we quantified and characterized AM over one year using acoustical and meteorological data measured at three locations near three wind farms. We found that the diurnal variation of outdoor AM prevalence was substantial, whereby the nighttime prevalence was approximately 2 to 5 times higher than the daytime prevalence. On average, indoor AM occurred during the nighttime from 1.1 to 1.7 times less often than outdoor AM, but the indoor AM depth was higher than that measured outdoors. We observed an association between AM prevalence and sunset and sunrise. AM occurred more often during downwind and crosswind conditions. These findings provide important insights into long term WFN characteristics that will help to inform future WFN assessment guidelines.

Thank you.

Julie Clarkson-Gulick

Pullman

Sent from Outlook

Health Effects of Wind Turbines: Testimony of Ben Johnson versus MidAmerican Energy (Madison County, Iowa)

By Sherri Lange -- August 23, 2019

> *"The annoyance of sight and the heard pulsating wind turbulence creates indirect adverse health effects. This combined with the direct effects of sleep disturbance may activate the body's autonomic nervous system to increase sympathetic-mediated responses with endocrinological consequences."*
>
> *"Increasingly activated, risk factors that promote adverse cardiovascular consequences may then promote/facilitate/enhance cardiovascular disease – most easily named as hypertension, arteriosclerosis, ischemic heart disease and stroke."*
>
> *– Ben Johnson, Testimony before the Madison County Board of Health, Madison Country, Iowa.*

I-27

Individuals and communities are collectively reporting the same NOCEBO effects, (https://www.merriam-webster.com/dictionary/nocebo) heart palpitations, ringing in the ears, dizziness, nausea, disorientation, sleep disorders, and other disorders from nearby industrial wind. There is no global conspiracy, there is only a mountain of data (data is when you have enough anecdotes) contradicting the narrative that such wind power is clean, safe and free.

Pro-developer witnesses lined up recently at the Iowa Madison County Board of Health's hearing into wind turbines and health, led by the Iowa Policy Project and the Iowa Environmental Council. Their nine-page, "Wind Turbines and Health" (https://www.iaenvironment.org/webres/file/iec_wind_health_paper_2019_final.pdf) referenced Fiona Crighton (nocebo effect), (https://waubrafoundation.org.au/2017/waubra-foundation-statement-re-simon-chapman-fiona-crichtons-book/) and Dr. Robert J. McCunney (https://windfarmrealities.org/?p=548) (known for his voluminous rapid-fire testimonies on behalf of wind companies). Their thesis: *if you are being reimbursed by the wind turbine company, or hosting, you are much less likely to experience health impacts*.

McCunney's critical review of 2014, states that he received funding from the Canadian Wind Energy Association but that it was all nicely arm's length and editorially free of any conflict-of-interest. Other dubious references inside the Iowa Policy Project-sponsored report attempt to validate findings by the Canadian Council of Academies, (http://www.na-paw.org/pr-150416.php) the book end review of wind turbine impacts to the Health Canada bogus study (https://patch.com/massachusetts/falmouth/health-canada-s-flawed-wind-turbine-fraudulent-health-study). Some have called these reference materials, studies, reviews, disingenuous, even fraudulent.

These "findings" by conflicted persons, reporting for government agencies and directly for developers and CanWEA or AWEA, find their way through the cooperating, often unknowing persons, in policy and permitting systems: in this instance, the Madison County Board of Health hearings.

Dr. Ben Johnson, Cardiologist, IOWA

Enter Iowa Cardiologist Dr. Ben Johnson (https://www.iowaheart.com/for-patients/find-a-provider/detail/?id=72), testifying *pro bono* on the meticulous research behind the "guidelines" recently provided (https://www.masterresource.org/wind-turbine-noise-issues/wto-wind-turbine-noise-as-a-health-hazard/) by the World Health Organization (WHO).

WHO advocates a political and moral standard (https://www.windturbinesyndrome.com/2011/) that encourages the burden of proof to fall upon those advocating for a possible challenge to impacts to health. The burden of proof has never rested with the industry: it has fallen on the victims of wind, and their advocates, to prove and test on their own homes, document health impacts for themselves, livestock, pets, and wildlife. Despite the magnitude of the complaints, the similarity, and the universal nature of the harm, the industry continues to provide "experts," paid consultants whose shabby appearance of scientific endeavor continue to insult not only victims, but also the real science, and true advocates who provide clarity and conscience.

The Board of Health of Madison County, Iowa passed a resolution last week recommending a 1.5-mile setback to protect residences from wind turbine nuisances and harms.

The following excerpts from Dr. Johnson's testimonies (three) relied on his expertise and study of Adverse Health Effects (AHE) based on his specialty, Cardiology. His CV is about electrophysiology – pacing and defibrillator technology, clinical trials, failed implantable lead technology and developing (with industry) new technologies- -particularly optimizing implantable devices to improve heart performance.)

Dr. Johnson provides the following conclusions to MasterResource.

Industrial Wind Turbines and Adverse Health Effects:

High Level Summary of the Issues:

1) Health – defined (WHO – 2001)

Health should be regarded as a "state of complete physical, mental and social wellbeing and not merely the absence of disease or infirmity." Note that this would include not only serious health disease — cardiovascular disease, hypertension, insulin-resistance — but also most of the described consequences of wind-turbine annoyance that affect mental and social well-being and contribute to physical debilities.

2) Annoyance: By itself, is considered as having adverse health effects

Noise is the principle impactor, but visually mediated and psychological adverse reactions are frequent causing health impacts to people living in the vicinity of wind turbines.

Cognitive effects are also associated with noise exposure. These include reading, concentration, memory and attention issues. Chronic noise exposure impairs cognitive function (reading comprehension and long-term memory) and a dose-response relationship between the two is supported by both laboratory and field studies. Over 20 studies have reported that noise adversely effects children's academic performance.

3) Concept of Noise and Sleep Disturbance

Noise pollution in our towns and cities in increasing. More than a nuisance, excessive noise is a health risk. As stated in the WHO 2018 guidelines, "noise is unpleasant and effects the quality of life." It disturbs and interferes with activities of the individual, including concentration, communication, relaxation and sleep.

Besides the psycho-social effects of community noise, there is concern about the impact of noise on public health, particularly regarding cardiovascular outcomes. The auditory system is **continuously** analyzing acoustic information, which is filtered and interpreted by different cortical and sub-cortical brain structures.

Arousal of the autonomic nervous system and the endocrine system is associated with repeated temporal changes in biological responses. In the long run, chronic noise stress may affect the homeostasis of the organism due to dysregulation, incomplete adaptation and/or the physiological costs of the adaptation. Noise is considered a nonspecific stressor that may cause adverse health effects in the long run. Such noise may be associated with disordered sleep.

Serious scientific studies of human sleep only began about 50 years ago. According to the restorative theory of sleep, body tissues heal and regenerate during non-REM sleep — particularly stages 3 and 4 associated with predominately slow-wave activity. Brain tissue "heals" during REM sleep and memories of the prior day's events becomes more "permanent". Interruption of the mostly ordered transitioning between/to deeper stage sleep by noise can occur with awakenings (>15 secs – associated with subsequent recollection) or with arousals (<15 seconds that may be repetitive and not acknowledged by affected sleeper).

Such recurrent sleep disruptions lead to non-restorative sleep with subsequent activation of the autonomic nervous system. More-heightened sympathetic activation triggers multiple downstream physiologic consequences — hypertension, insulin resistance and complex atherosclerotic vascular disease which may promote plaque build-up and increase potential consequences of fatal and non-fatal heart attacks, angina, stroke and heart arrhythmias.

Indeed, there has been a surge in the incidence of atrial fibrillation (AF) — a fast, chaotic atrial arrhythmia. AF is very frequently associated with obstructive sleep apnea which triggers sleep arousals (among a myriad of other consequences) that

lead to non-restorative sleep. Untreated patients with sleep apnea commonly have hypertension, various degrees of insulin resistance and a higher incidence of vascular disease. It is truly remarkable how patients may deny any "trouble sleeping" but suffer from severe sleep apnea that may be amenable to treatment. Treatment in an affected population leads both to less AF and is associated with a decrease the prevalence of associated cardiovascular disease.

Sleep disturbance is reported for those who **report hearing** wind turbine sound. IMPORTANTLY, there are other disease states where disrupted sleep is triggered by non-awakening "arousals" (e.g. due to apneic/brief hypoxic events associated with obstructive sleep apnea). Similarly, there are recent pilot studies and now ongoing research measuring the observed physiologic changes of accurately reconstructed sound emissions (frequency and loudness) produced during formal sleep studies. **The pilot studies suggest that the unique properties of wind noise do adversely affect some aspects of normal sleep architecture.** (*Our emphasis)*

4) Infrasound and Low Frequency Noise (ILFN)

It has been established for nearly 35 years, that industrial turbines emit infrasound (<20 Hz) and low-frequency noise (<160 Hz). Analyzed frequency and sound pressure characteristics of industrial wind turbines emission has shown the emitted sound content (noise) to have these frequencies.

Wind turbine noise is complex, highly variable and has unique characteristics. The amount and type of sound emitted by a wind farm at a given time and in a given location is influenced by many variables including topography, temperature , wind speed, turbine design, the extent to which they are maintained, the number of turbines and their mode of operation.

It has also been established via multiple means of evaluation that the brain can "sense" infrasound as a tonal frequency transitions to a perceptible vibratory quality as the sound frequency lessens. Generally 35-40 dB are described as being needed to

"sense/hear" those low frequency noises. Interestingly, ILFN "loudness" may be greater indoors than outdoors at the same location and can cause a building to vibrate resulting in resonance.

A significant proportion of the sound emitted by wind turbines is in the lower frequency range, i.e., below 20 Hz. Humans are more sensitive to low frequency noise, and it can therefore cause greater annoyance than higher frequency sound. The dB(A) weighting (filtering) system is not designed to measure these lower frequency sounds and is not an appropriate way of measuring it. The best way to assess ILFN is to through "raw" unweighted measurements which are not averaged across time and then subjected to detailed "narrow-band" analysis.

5) Evolving Quantification of Societal Impact of Noise Emission

With the published October, 2018 WHO statement, **DALYs** (Disability-Adjusted Life-Years — which is the sum of years of life lost due to ill-health, disability or early death) have been calculated. One DALY is equivalent to one year of health life lost.

Given measured sound exposures and their exposures to inhabitants in European Union cities, the WHO estimates that 1-1.6 million health life years are lost from traffic noise. Sleep disturbance and annoyance related to traffic noise comprise the main burden (903,000 DALYs for sleep disturbance; 654,000 DALYs for annoyance; 61,000 for ischemic heart disease and 45,000 for cognitive impairment). *Clear sleep disturbance is the largest mechanism of harm due to environmental noise.*

Rural Iowa does not have significant "background traffic, aviation or train sound emissions," but could have significant ongoing turbine sound emissions which (although not quantified yet) could, being another environmental noise, reach the impacts like those DALY consequences noted above.

Relatively fewer people are exposed to industrial-size wind turbines, but those individuals would still be experiencing sound emissions with potentially adverse

health effects. Unfortunately, the consequences would be greater for the more vulnerable parts of society — the young and elderly.

6) Why don't we know **for sure** regarding the health impacts?

Wind Energy has never proven that exposure to industrial wind turbines is safe.

The 2018 WHO statement, for the first time, listed industrial wind turbines as a source of environmental noise and carefully weighed the available data. There were no studies at the time of statement publication to assess the incidence of ischemic heart disease, nor hypertension among other endpoints.... the studies simply had not been done with those studies being quite complex to perform. Indeed, in section 3.4 of the 2018 WHO statement, evidence quality was specifically written as "no studies were available" acknowledging that there was no available data (yet) to confirm an association of sound to adverse cardiovascular outcomes.

The WHO's turbine noise "conditional" rating of "strength of recommendation" for implementing guidelines reflects a policy-making process with substantial debate and involvement of various stakeholders. Recommendations are rated as either strong or conditional.

In accordance with the prioritization process, the GDG (Guidelines Development Group), set a guideline exposure level of 45 dB L(day-evening-night) average reflective of analysis of an exposure-response curve of four available studies from "highly annoyed populations" showing significant higher adverse health risks above 45 dB.

They felt unable to specify a lower night sound emissions level (during sleep — where sleep disruption is more critical). *This omission has been widely criticized by anti-wind factions. Indoor/open-window nighttime sleeping sound levels are best at <33 dB) (Our emphasis)*

Another health concern from turbines is the potential harm from radio/ electromagnetic exposure emitted by the turbines. This is debated globally. Authors who have voiced their concern of health safety over this have recommended that governmental regulators advise the public of potential risks of exposure and establish limits that incorporate all sources of radio/electromagnetic energy, including wind turbines. They further state: "Until these limits are established, governments should take precautionary and proactive measure to protect public health..."

Similarly, the public and landowners placed at direct and immediate risk of catastrophic turbine failure, have not been provided with recommended radius safety-zone dimensions specific to the Vestas, Model 1100 — which is the turbine model proposed for Madison County.

Despite repeated requests, this critical safety information remains unknown, even in public hearings when MAE (MidAmerican Energy) and Madison County officials who are responsible for public safety are directly questioned. This is relevant in that the last (smaller) model of IWTs (Industrial Wind Turbines) did have guidelines published.

Concerningly, there may be future replacement of existing MAE turbines with larger, more powerful models (on the fixed, existing pedestals). Reportedly, that possibility of up-sizing turbine capacity is reflected in recent Adair County planning minutes (https://www.wind-watch.org/news/2018/10/27/adair-county-supervisors-pass-turbine-resolution/) for the turbines placed there. Such larger turbines would likely increase the strength of the emissions and, with that, increase the endpoints of incidence and prevalence of turbine-related adverse health effects.

7) At the second of three Madison County public hearing on the variance request by MAE, comments made by the MAE engineers/representatives included that :

1) they "never" assess sound by means other than A-weighting analysis. Because

humans cannot hear sounds <20 Hz.

2) they "never" measure any sounds from within the house – "only to the front door"

3) Sound intensities (pressures) from the proposed turbine sites are "calculated." Only upon recurrent resident requests, will they come to acquire actual sound measurements.

4) They commented that the WHO publications on environmental noise were "getting crazy"

Their industry-paid consultant neurologist/sleep specialist from Boston also spoke at a BOA (Board of Adjustment) meeting, noting:

1) symptoms of annoyance (depression, hopelessness, nausea, vertigo, etc.) could not be associated with the presence of the turbines alone but likely reflect a non-associated separate medical problem

2) he felt it was impossible that ILFN would travel that far from the turbine to actually cause sleep disruption.

All those points are rejected in the most current medical literature. And these points have been included/itemized in successful legal judgements against Wind Energy defendants when reviewing adverse health effects to affected residents.

8) Indeed, data is accumulating about the pivotal but insidious connection of environmental noise causing sleep disturbance and cardiovascular disease.

(These studies are included on page #4 of summarizing information I provided to The Madison County Board of Health). In a more detailed description of the impact of environmental sound, Dr. Dominguez noted a "graded response" of objectively measure vascular disease and quantity and quality of sleep. Extensive multivariate

analysis was performed to adjust for a wide range of confounding variables. The presenter noted that the more average times an individual awoke per night, the greater number of vascular plaques were documented. Dr. Fountas did a meta-analysis review of 11 prospective studies correlating self-reported daily sleep duration and cardiovascular morbidity and mortality of over one-million patients without clinical baseline cardiovascular disease that were followed an average of 9.3 years. Those sleeping <6 hrs or >8 hrs had a higher risk of fatal or non-fatal cardiovascular disease compared to those sleeping 6-8 hours which is considered a normal amount to achieve restorative sleep. Longer sleep duration was felt by the authors to possibly reflect morning exhaustion prompting additional sleep hours to "catch-up".

With that idea of "sleep catch-up," notable is a *Journal of the American Medical Association* article published about a month ago that suggested that those who attempted "sleep catch-up" on the weekend actually may have even worse outcomes than those who just resume a "normal" sleep pattern. This was measured by tests of insulin resistance that most directly varies with adrenalin responses to stress. (That article was given to the Madison County Board of Health at their most recent every two-month meeting). Elevated serum insulin levels due to adrenergically-driven insulin resistance is felt to be one of the consequences of sleep disturbance.

9) Recognizing that complete data is lacking to definitely link industrial wind turbines with adverse health, I cite Wind Energy's apparently sponsored University of Iowa expert panel of the scientific evidence regarding various complaints (which) led to several conclusions (Wind Turbines and Health, Thorne, Osterberg, Johannsen):

1) The current evidence is **sufficient** to establish a causal relationship between a person's exposure to wind turbine noise and feelings of annoyance.

2) The current evidence is **limited** for a causal relationship between exposure to wind

turbine noise and sleep disturbance. The panel defined "limited" of a causal relationship **as plausible**, but that chance, bias and confounding factors could not be ruled out with reasonable confidence. This is in keeping with the WHO stance noted above.

I would ask you, why would you erect a very expensive, contentious (highly to some), greater than 500 foot high tower– with large moving blades without a stated safety radius by the manufacturer, that reportedly will operate for nearly 40 years *(Editor's Note: turbines rarely survive the stated working life of 20 years, and begin to degrade and require repairs and experience serious lost performance between twelve years and fifteen years* (https://www.ref.org.uk/attachments/article/280/ref.hughes.19.12.12.pdf)) and that has never been proven to safe nor free of adverse health effects, that **possibly (it is plausible)** will cause sleep disturbance and that will likely contribute to some degree of future cardiovascular disease in the nearby affected citizens who had very little to say about it? This when other technologies are available with essentially no health risk (photovoltaic)?

Finally, recognizing someone who has spent his entire professional career reviewing evidence that Wind Turbines Pose Risks, Jerry Punch, (https://hearinghealthmatters.org/hearingviews/2014/wind-turbine-noise-evidence-health-problems/) Professor emeritus from Michigan State University who recently wrote a peer-reviewed 72-page article that addressed each of two wind energy claims and positions stated the following:

> *the available literature, which includes research reported by scientists and other reputable professionals in peer-reviewed journals, government documents, print and web-based media and in scientific and professional papers presented at society meetings, is sufficient to establish a general causal link between a variety of commonly observed adverse health effects and noise emitted by industrial wind turbines.*

Returning to the 2001 WHO statement in the first paragraph above defining health, "health" is viewed as beyond an absence of acquired physical disease, it also includes mental and social wellness. The mere presence of these huge turbines placed, as proposed, in close proximity to our county residence creates lasting annoyance in at least 20% of those exposed at the proposed siting distances.

Hopefully you are aware of the social outcry of your county against the intrusion of these unwanted disturbances. The annoyance of sight and the heard pulsating wind turbulence creates indirect adverse health effects. This combined with the direct effects of sleep disturbance may activate the body's autonomic nervous system to increase sympathetic-mediated responses with endocrinological consequences.

Increasingly activated, risk factors that promote adverse cardiovascular consequences may then promote/facilitate/enhance cardiovascular disease – most easily named as hypertension, arteriosclerosis, ischemic heart disease and stroke.

Importantly:

1) Does this **prove** that "wind turbines" cause disease? — **NO**

2) Has Wind Energy ever shown that wind turbines are safe and free of adverse health effects? **Absolutely Not**

3) There is an enormous amount of scientific data to suggest that wind turbines may **possibly** cause adverse health effects. As noted above, the U of I paper likely paid for by the Wind Energy faction **AGREES that there is a plausible causal relationship between exposure to wind turbine noise and sleep disturbance.**

The scientific data is rapidly accumulating and getting us closer to absolute confidence that wind turbines "cause disease." It will be an association, like all disease prevalence, that is statistical… the large numbers needed to prove a correlation that are adjusted for confounding variables in exposed populations

with highly predictive statistical significance, are hard to obtain.... but the data is coming.

Wind Energy could do the research needed by exposing monitored residence living various distances from the wind turbines in large enough numbers to meet anticipated statistical significance. All disease-markers/endpoints variables would be catalogued and measured consistently over at least 20 years. All these "test (treated) groups" would be compared with matched control groups without wind turbine exposure and monitored for the same disease process in the same method as the actively "treated" groups. This study would require a supervising Investigative Review Board to protect the test subjects. It would require informed consent from the study participants. Having been a Chairman for the Des Moines Area Investigative Review Board where conducted human research proposals are reviewed, approved and monitored, I seriously doubt that such a study could be done. This is because the health consequences are not completely known, but what is known is adverse in nature (thus making informed consent not possible) and the participants may not derive potential benefit from the study (the EXACT situation for the Madison County residents who would be forced to live with turbine presence) among many other considerations.

Such a pattern of increasing possibility/likelihood and linked causality in our scientific, world-wide evaluations of potential adverse health effects from wind turbine noise and annoyance is impressive. The Oct 2018 WHO report reflects that opening of scientific understanding and the evolving clarification of that risks. The lack of respect for this data by Wind Energy is equally impressive.

I ask you to speak for your neighbors, your family, your community, and for the impacts of Wind Energy will have in future generations, and to those who look to you in your elected position of leadership. Protect the citizens of Madison County against the possibly harmful effects of Wind Energy development as currently proposed by Mid-American Energy. (*Bold is the author's emphasis)*

Respectfully, W. Ben Johnson, M.D. Cardiologist/Electrophysiologist, Des Moines, Iowa

Update: WINTERSET, Iowa *—The Madison County Board of Health says there is the potential that wind turbines could be bad for your health. The board passed a resolution recommending that any future turbines be built at least a mile and a half from non-participating homes.*

21 Comments

SegueC () • August 23, 2019 at 3:00 pm

The dedication of the good Doctors on the right side of history in the fight to preserve the health and safety of rural residents afflicted by wind industry torture restores faith in humanity. Their courage is also admirable.

Reply

steven cooper (http://acoustics.com.au) • August 23, 2019 at 4:15 pm

Examination of the Crichton material will find that the test signal was NOT the infrasound signal that is commonly attributed to wind trubines. The signal was not one of pulsations and was a single tone (5 Hz in one experiment and 9 Hz in another).

Hence the title of the paper is incorrect as the testing was not of wind turbine infrasound.

Hence the concept of Nocebo as presented by Crichton becomes questionable.

I have spent years investigating the actual acoustic signature of wind turbines and as a memeber of the Acoustical Society of America's Wind Turbine Working Group have presented multiple papers as to the techical aspects of the acoustic signature.

Because of the short time span of the puslations it is questionable if there is actually infrasound in the sense of a tone.

Pulsations that occur at rate less than 10Hz were defined by Zwicker and Fastl as "fluctuations". Fluctuations are sensed by the body – not heard.

Persons sensitised to wind turbine noise can identify in the laboratory the prescence of the test signal even when they cannot hear it (see paper to ASA in New Orleans in Dec 2017).

New material in relation to the Crichton "Nocebo" is to be presented in two weeks at the 2019 Internaltional Congress on Acoustics in Germany.

Reply

Sherri Lange () • August 23, 2019 at 4:21 pm

Thank you, Segue. This meaningful comment reminds me of the other doctors, medical personnel, researchers, of the mindset to tell the truth, and explore wind lies as well. Some are listed in the WHO letter to the (World Health Organization), and the list of Quebec physicians, writing for a moratorium, and also the French Academy of Medicine, similarly declaring wind turbines a "nuisance," asking for a full stop.

https://www.windturbinesyndrome.com/2011/40-doctors-sign-wind-turbine-syndrome-petition-quebec/ (https://www.windturbinesyndrome.com/2011/40-doctors-sign-wind-turbine-syndrome-petition-quebec/)

Add Dr Ben Johnson, who took likely hundreds of hours to research and present not once, but three times, to his local Board of Health, Madison County.

A substantial list of deniers, mercifully now discredited, can be found on the Waubra Website, 2014. More can be added, certainly. But the accruing numbers of physicians, experts, now in the hundreds and multiples of hundreds, show us that right will stand up to might.

Dr Hallstein, of Falmouth, MASS, is quoted by Waubra:

"There is extensive clinical experience and a body of peer reviewed research evidence, which supports clinical concerns about the adverse health consequences of both chronic sleep deprivation, and chronic stress, regardless of the specific cause of that sleep deprivation or stress. 54,55,56,57 Dr William Hallstein, a psychiatrist from Falmouth, USA stated the following in a recent letter to the Falmouth Board of Health 58:

"In the world of medicine illnesses of all varieties are destabilized by fatigue secondary to inadequate sleep. Diabetic blood sugars become labile, cardiac rhythms become irregular, migraines erupt and increase in intensity, tissue healing is retarded, and so forth, across the entire field of physical medicine. Psychiatric problems intensify and people decompensate. Mood disorders become more extreme and psychotic disorders more severe."

"Those who are young and fit report taking longer to be adversely impacted by exposure to wind turbine noise, unless they have underlying physical and mental health conditions or acknowledged risk factors such as a history of migraines, inner ear pathology or motion sickness, which make them more vulnerable or susceptible."

Reply

Sherri Lange () • August 23, 2019 at 4:27 pm

Thanks, Steven Cooper. We are all looking forward to receiving news of your upcoming presentations in Germany at the International Congress on Acoustics. I hope you will let us interview you again. Fiona Crichton also is of the fame that: wind turbine "syndrome" is a "communicated disease." Of course, that theory has gone down now with a solid "THUD" in the world of victims and experts.

Thank you again, very sincerely, for all you do, to expose a more meaningful Language and Understanding of the multi faceted pieces of wind turbine 'noise.'

Reply

Sommer () • August 24, 2019 at 2:15 pm

Listening to the raw truth from people reporting harm from turbines, that are sited too close to their homes, and watching the deterioration of health has been a devastating experience. These people chose to live in the quiet countryside in 'deep silence' in order to optimize their mental and physical health. They chose to be close to nature for their well being. They did not consent to being harmed!

Cardiovascular related episodes, caused by surrounding turbines, when barometric pressure fluctuations and certain wind speeds occur, are downright traumatizing. Anecdotal reports ought to be more than enough to cause ethical people to demand that these turbines be turned off.

And forced relocation is absolutely unacceptable. Anyone suggesting that people leave their homes is complicit in this crime.

Many medical people have not made the connections between people reporting well known psychological and physical symptoms of harm and the turbines in their communities. Instead these doctors are prescribing drugs to mask the symptoms. These drugs can have serious side effects and lead to iatrogenic disease.

This is a human rights violation and those who are being harmed should not have to endure further harm and stress trying to satisfy legal or scientific requirements to validate their harm. This is also a violation of the Nuremberg Code. Kurt Devlin was right about this!

The harm from LFN and infrasound, according to expert, Dr. Mariana Alves-Pereira, is both cumulative and irreversible. She has publicly declared that knowing what she knows about the harm, she would not live within 20 km from wind turbines!

Only those who have genocidal ideology toward rural residents, who are forced to live with these turbines, would insist on having people who are honestly reporting harm, waste vital time and energy proving it somehow.

Both the legal and scientific process to prove harm is within a 'rigged box' designed to delay… delay… delay. These delays have serious consequences.

The liability for those who are responsible for this harm, at a moral level, must be/will be fully realized.

People who acknowledge their birth right to act out of free will and follow their conscience understand this clearly.

True advocates for people being harmed act out of courage and a sense of urgency.

Reply

Sherri Lange () • August 24, 2019 at 9:32 pm

Thank you, Pauli. And thank you for organizing with Professor Mann, the upcoming event at the University of Waterloo with Mariana Alves-Pereira. She is a brilliant communicator. I pray they will receive records and reports from their testing at homes and so on, if that is what they are agreeing to. I am sure Ms Alves-Pereira will respond appropriately and accept the challenge of the acoustic testing demands, which are complex and varied. As noted, this is a professor with vast knowledge of VAD (Vibro Acoustic Disease) and ILFN. Anyone lucky enough to hear of her studies and findings is very fortunate.

More and more, people are finding physicians like Dr. Ben Johnson, who are ringing the bell for honesty, and who are finding the tentative or very concrete relationships between sleep deprivation and chronic or advancing disease. We are very grateful for this kind of pro bono testimony. It is so purely driven, and offered with the intent of helping his IOWA Coalition, and more beyond that.

Reply

Falmouth 110 Db Wind Turbines For Sale Setbacks 1.5 Miles - admin (https://mysleephygiene.com/falmouth-110-db-wind-turbines-for-sale-setbacks-1-5-miles/) • August 25, 2019 at 8:44 am

[…] https://www.masterresource.org/wind-turbine-noise-issues/health-effects-of-wind-turbines-testimony-o&#8230 (https://www.masterresource.org/wind-turbine-noise-issues/health-effects-of-wind-turbines-testimony-o&#8230); […]

Reply

Michael Spencley () • August 28, 2019 at 1:58 pm

The overwhelming and constantly mounting scientific and medical evidence linking industrial wind turbines to very serious (and sometimes catastrophic) health effects is well sampled in this article by the author, Lange.

Dr. Ben Johnson, a Cardiologist, from Iowa, has given testimony before the Madison County Board of Health, Madison Country, Iowa, in the form of a well-articulated treatise covering the known health dangers. The bravery of a medical specialist like Dr. Johnson, going on record without remuneration to sound the warning and an altruistic cry for protection and justice against the industrial wind turbine catastrophy is the stuff of "David and Goliath" and quite extraordinary. He is one of the well respected, independent and unpaid Cardiac experts that will surely face the wrath of the "Green Brigade" (those who try to bury the health problems caused by industrial wind turbines).

I applaud Dr. Johnson's initiative and I applaud Master Resource and Sherri Lange for continuing to document the evidence and call the wind lobby's farcical bluff.

Reply

Sherri Michael () • August 28, 2019 at 2:13 pm

Many thanks, Michael Spencley. Praise is indeed due: important to note that likely every person on the pro side of the project testifying at the Board of Health, was remunerated. Not the witnesses against, nor of course Dr. Johnson.

I am very impressed with the wide scope of reading and study that Dr Johnson did in order to prepare. One needs to zig zag between the last 30 or so years, and then weight the evidence. It is overwhelming now. And the link to cardiac health, or not, is key to our understanding of basic survival and health. Many that we hear of, have family members who have suffered cardiac events since turbines have arrived in their community. Of course it is not all about the heart. It is also every organism and mechanism of health and life.

"The Golden West Wind Energy Center in Calhan, Colorado, which consists of 145 453-foot tall industrial wind turbines, has been fully operational since October 2015. Residents living within the wind farm project's footprint have reported negative physical and psychological effects from the turbines. Concern has now shifted to the suspected effects the turbines are having on the animals in the area.

According to the September 2015 issue of "The New Falcon Herald," the effects on humans range from dizziness and nausea to concerns about dirty electricity and the potential for the electromagnetic waves to cause an irregular heartbeat, or atrial fibrillation.

Domestic animals are in grave danger, too, based on worldwide accounts."

Thank you.

Reply

Sommer () • August 28, 2019 at 4:42 pm

This event has been arranged by Professor Richard Mann at the University of Waterloo.

Speaker: Mariana Alves-Pereira

Title: Infrasound & Low Frequency Noise: Physics, Cells, Health and History

Date: Thursday September 12, 2019

Time: 1 pm

Location: University of Waterloo

Room: DC 1302 (Davis Center)

Speaker Bio:

Mariana Alves-Pereira holds a B.Sc. in Physics (State University of New York at Stony Brook), a M.Sc. in Biomedical Engineering (Drexel University) and a Ph.D. in Environmental Sciences (New University of Lisbon). She joined the multidisciplinary research team investigating the biological response to infrasound and low frequency noise in 1988, and has been the team's Assistant Coordinator since 1999. Recipient of three scientific awards, and author and co-author of over 50 scientific publications (including peer-reviewed and conference presentations), Dr. Alves-Pereira is currently Associate Professor at Lusófona University teaching Biophysics and Biomaterials in health science programs (nursing and radiology), as well as Physics and Hygiene in workplace safety & health programs. Mariana Alves-Pereira can be readily reached at: m.alvespereira@gmail.com (mailto:m.alvespereira@gmail.com).

Reply

Sherri Lange () • August 31, 2019 at 2:13 pm

Thank you, Pauli Sommer. This is an important event and we hope that participants/ attendees will include politicians who have been invited from the Ontario Legislature.

Reply

Mark Twichell () • September 8, 2019 at 11:45 am

I'm so thankful for the testimony of Dr. Ben Johnson and its publication on this site. As usual the quality of comments here is outstanding. The contributions of Steven Cooper and Mariana Alves-Pereira will be further augmented by their presentations in Germany and Ontario respectively. On that note I wish to share announcement of a Wind Turbine Noise/ Public Health Discussion co-sponsored by NYS Senator Robert Ortt and wind opposition group Save Ontario Shores. The event will feature presentations by audiologist Dr. Jerry Punch and acoustician Robert Rand. Additionally, environmental attorney Gary Abraham will speak about the intersection of wind turbine noise concerns and NY State wind turbine permitting policy. Negatively impacted wind turbine neighbors from across NY State will give brief statements of their experiences of adverse health effects. This panel discussion is the first of its kind in NY State. It is scheduled from 4 to 6 pm at Erie Community College North Campus, 6205 Main St., Williamsville, NY , Gleasner Hall Auditorium. Parking and admission are free.

Reply

Sherri Lange () • September 24, 2019 at 9:33 am

Thank you, Mark. Dr. Mariana Alves-Pereira gave a wonderful, as usual, presentation. This is available for viewing on this link. She urged people who are impacted to leave their homes at least for respite trips, but also to consider long term exposures and how much they could manage it. Dose response seriously important.

Please also send us the link for the presentation in NY organized by Save Ontario Shores?

Talk:

https://uwaterloo.ca/computer-science/events/seminar-infrasound-and-low-frequency-noise-physics-cells (https://uwaterloo.ca/computer-science/events/seminar-infrasound-and-low-frequency-noise-physics-cells)

Webcast ("Live Stream"):

https://livestream.com/itmsstudio/events/8781285 (https://livestream.com/itmsstudio/events/8781285)

Reply

LETTER FROM DR. MAARTEN BOKHOUT, ACTING MEDICAL OFFICER OF HEALTH, HURON PERTH, LETTER TO RESIDENT CARLA STACHURA: A shameful exhibit of carelessness, callousness, and/or negligence? | Great Lakes Wind Truth (http://greatlakeswindtruth.org/newsworthy/letter-from-dr-maarten-bokhout-acting-medical-officer-of-health-huron-perth-letter-to-resident-carla-stachura-a-shameful-exhibit-of-carelessness-callousness-a) • September 24, 2019 at 10:26 am

[…] Please also note his reference to the newly minted cautions by the Madison County Board of Health. Clearly he has read the work of Dr. Ben Johnson, whose testimony certainly led to the Board's decision to request larger setbacks. See excerpt below, Dr Johnson quoted on Master Resource. […]

Reply

LETTER FROM DR. MAARTEN BOKHOUT, ACTING MEDICAL OFFICER OF HEALTH, HURON PERTH, TO RESIDENT CARLA STACHURA: A shameful exhibit of carelessness, callousness, and/or negligence? | Great Lakes Wind Truth (http://greatlakeswindtruth.org/newsworthy/letter-from-dr-maarten-bokhout-acting-medical-officer-of-health-huron-perth-letter-to-resident-carla-stachura-a-shameful-exhibit-of-carelessness-callousness-a) • September 24, 2019 at 5:16 pm

[…] Please also note his reference to the newly minted cautions by the Madison County Board of Health. Clearly he has read the work of Dr. Ben Johnson, whose testimony certainly led to the Board's decision to request larger setbacks. See excerpt below, Dr Johnson quoted on Master Resource. […]

Reply

Sherri Lange () • September 25, 2019 at 1:57 pm

https://www.kcci.com/article/madison-county-to-decide-on-wind-turbine-setbacks/29204876# (https://www.kcci.com/article/madison-county-to-decide-on-wind-turbine-setbacks/29204876#)

WINTERSET, Iowa —

Madison County Supervisors on Tuesday approved a second reading of a proposal to enforce wind turbine setbacks on solar energy projects.

The proposal will get at third and final reading in two weeks.

September 24, 2019

Reply

Wind Turbines in Court: What Are the Issues? - Master Resource (https://www.masterresource.org/uncategorized/wind-turbines-in-court-what-are-the-issues/) • October 3, 2019 at 8:08 am

[…] given the general pushback in North America by communities, public health agencies such as Madison IOWA, declaring that wind turbines can cause harm, and arguing for larger setbacks. With Facebook and […]

Reply

noname (https://elpais.pro) • November 19, 2019 at 12:03 pm

The Madison County Board of Health says there is the potential that wind turbines could be bad for your health. The board passed a resolution recommending that any future turbines be built at least a mile and a half from non-participating homes.

Reply

Al Schafbuch () • June 12, 2022 at 9:34 pm

There needs to be a moratorium on all wind turbines in the United States.

Restart coal and start approval of Safe Nuclear power plants.

Reply

Lonnie Appleby () • March 21, 2024 at 5:05 pm

I'm still trying to figure out how wind turbines cause all of these issues, yet the hundreds of thousands (if not millions) of cars that pass along I-80 every year (which I can clearly hear from my current home and could from my childhood home…the sound used to lull me to sleep on hot, humid summer nights with the windows open) are not responsible for this also. We have had the Eisenhower Highway System in place for how many decades now? I know president Trump tried to make these a bogey man by claiming they make a noise that sounds like, "RRRRrrrr RRRrrrrrr." Having stood directly below one as the blades were whizzing past, I can attest that they made a "WHOOOOfffff WHOOOOffff" sound and nothing more that I could detect. If noise causes all of these issues, we had better stop construction of skyscrapers, because the noise generated from construction can be deafening when you walk directly past a site; and having worked in buildings next to a 35-story building going up, you hear the noise all day long. My ticker is still going strong. We all hear and believe what we want to hear and believe. I, however, speak from my own experience with constant traffic noise from I-80 in Newton from age 4 to day (that totals 51 years of nearly constant traffic noise…it did shut down for a major accident and some snow storms over the years) and from standing directly beneath a spinning turbine. I can only tell you what I know from personal experience…and I take studies and opinions with a shaker of salt these days. By the age of 55, I know to trust my own "lying ears and eyes."
Reply

rbradley () • March 25, 2024 at 9:33 pm

Industrial wind turbines, first of all, are creatures of special government favor and wound the grid by their dilute, intermittent nature. They are an intrusion on nature from politics.

There is permanent noise and light flicker, and other nuisances are present. The neighboring home owners report a lot of negatives from the enormous structures. That is why a 'civil war' is going on at the grassroots from on-the-spot environmentalists.

Reply

Leave a Reply

Name (Required)

Mail (Will Not Be Published) (Required)

Website

SUBMIT COMMENT

Share This Article

Search This Site

To Search, Type & Hit Enter

Principals

Robert L. Bradley, Jr. (https://www.masterresource.org/about#btruth)

Roger Donway (https://www.masterresource.org/about#roger-donway)

Kassie Andrews (https://www.masterresource.org/about#kandrews)

John Droz, Jr. (https://www.masterresource.org/about#john-droz)

Craig D. Idso (https://www.masterresource.org/about#craig-d-idso)

Mark Krebs (https://www.masterresource.org/about#m_krebs)

Joanna Szurmak (https://www.masterresource.org/about#pierre-and-joanna)

Featured Categories

Climate Change (https://www.masterresource.org/category/climate-change/)

State Energy Regulation (https://www.masterresource.org/category/state-energy-regulation/)

Corporate Governance (https://www.masterresource.org/category/corporate-governance/)

Wind Politics (http://www.masterresource.org/category/wind-politics/)

International (https://www.masterresource.org/category/international/)

Energy Sources (https://www.masterresource.org/category/energy-sources/)

Electricity Policy (http://www.masterresource.org/category/electricity-policy/)

AWED Newsletters Archive (https://www.masterresource.org/awed-newsletters/)

Contributors

Michael Lynch

Sherri Lange

Lisa Linowes

Kevon Martis

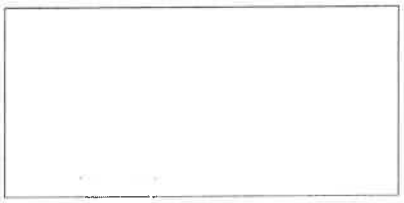
Bill Peacock

Tom Tanton

Jim Wiegand

ALL CATEGORIES (HTTPS://WWW.MASTERRESOURCE.ORG/CATEGORIES/)

ARCHIVE (HTTPS://
WWW.MASTERRESOURCE.ORG/2014/)



(https://
www.masterresource.org/
reading-list)

Blog Roll Link

American Energy Alliance (http://americanenergyalliance.org/)

Energy In Depth (http://energyindepth.org/)

GlobalWarming.org (http://www.globalwarming.org/)

Institute for Energy Research (http://instituteforenergyresearch.org/)

Knowledge Problem (http://knowledgeproblem.com/)

(https://www.masterresource.org)

A PROJECT OF THE INSTITUTE FOR ENERGY RESEARCH

ABOUT (HTTPS://WWW.MASTERRESOURCE.ORG/ABOUT/)

AWED NEWSLETTERS ARCHIVE (HTTPS://WWW.MASTERRESOURCE.ORG/AWED-NEWSLETTERS/)

CATEGORIES (HTTPS://WWW.MASTERRESOURCE.ORG/CATEGORIES/)

READING LIST (HTTPS://WWW.MASTERRESOURCE.ORG/READING-LIST/)

(/
() () feed/)

CFP·MFC
Official Publication of
The College of
Family Physicians of Canada

Can Fam Physician. 2013 May;59(5):473-475.

Adverse health effects of industrial wind turbines

Roy D Jeffery [1,✉], Carmen Krogh [2], Brett Horner [3]

Author information Copyright and License information

PMCID: PMC3653647 PMID: 23673580

This article is also available in French. See "Effets indésirables sur la santé des éoliennes industrielles".

Canadian family physicians can expect to see increasing numbers of rural patients reporting adverse effects from exposure to industrial wind turbines (IWTs). People who live or work in close proximity to IWTs have experienced symptoms that include decreased quality of life, annoyance, stress, sleep disturbance, headache, anxiety, depression, and cognitive dysfunction. Some have also felt anger, grief, or a sense of injustice. Suggested causes of symptoms include a combination of wind turbine noise, infrasound, dirty electricity, ground current, and shadow flicker.[1] Family physicians should be aware that patients reporting adverse effects from IWTs might experience symptoms that are intense and pervasive and might feel further victimized by a lack of caregiver understanding.

Background

I-28

There is increasing concern that energy generation from fossil fuels contributes to climate change and air pollution. In response to these concerns, governments around the world are encouraging the installation of renewable energy projects including IWTs. In Ontario, the Green Energy Act was designed, in part, to remove barriers to the installation of IWTs.[2] Noise regulations can be a considerable barrier to IWT development, as they can have a substantial effect on wind turbine spacing, and therefore the cost of wind-generated electricity.[3] Industrial wind turbines are being placed in close proximity to family homes in order to have access to transmission infrastructure.[4]

In Ontario and elsewhere,[5] some individuals have reported experiencing adverse health effects resulting from living near IWTs. Reports of IWT-induced adverse health effects have been dismissed by some commentators including government authorities and other organizations. Physicians have been exposed to efforts to convince the public of the benefits of IWTs while minimizing the health risks. Those concerned about adverse effects of IWTs have been stereotyped as "NIMBYs" (not in my backyard).[6,7]

Global reports of effects

During the past few years there have been case reports of adverse effects. A 2006 Académie Nationale de Médecine working group report notes that noise is the most frequent complaint. The noise is described as piercing, preoccupying, and continually surprising, as it is irregular in intensity. The noise includes grating and incongruous sounds that distract the attention or disturb rest. The spontaneous recurrence of these noises disturbs the sleep, suddenly awakening the subject when the wind rises and preventing the subject from going back to sleep. Wind turbines have been blamed for other problems experienced by people living nearby. These are less precise and less well described, and consist of subjective (headaches, fatigue, temporary feelings of dizziness, nausea) and sometimes objective (vomiting, insomnia, palpitations) manifestations.[8]

A 2009 literature review prepared by the Minnesota Department of Health[9] summarized case reports by Harry (2007),[10] Phipps et al (2007),[11] the Large Wind Turbine Citizens Committee for the Town of Union (2008),[12] and Pierpont (2009).[13] These case studies catalogued complaints of annoyance, reduced quality of life, and health effects associated with IWTs, such as sleeplessness and headaches.[9]

In 2010, Nissenbaum et al used validated questionnaires in a controlled study of 2 Maine wind energy projects. They concluded that "the noise emissions of IWTs disturbed the sleep and caused daytime sleepiness and impaired mental health in residents living within 1.4 km of the two IWT installations studied."[14]

Reports of adverse health effects[15] and reduced quality of life[16] are also documented in IWT projects in Australia and New Zealand.

A 2012 board of health resolution in Brown County in Wisconsin formally requested financial relocation assistance for "families that are suffering adverse health effects and undue hardships caused by the irresponsible placement of industrial wind turbines around their homes and property."[17]

An Ontario community-based self-reporting health survey, WindVOiCe, identified the most commonly reported IWT-induced symptoms as altered quality of life, sleep disturbance, excessive tiredness, headache, stress, and distress. Other reported effects include migraines, hearing problems, tinnitus, heart palpitations, anxiety, and depression.[18] In addition, degraded living conditions and adverse socioeconomic effects have been reported. In some cases the effects were severe enough that individuals in Ontario abandoned their homes or reached financial agreements with wind energy developers.[19]

After considering the evidence and testimony presented by 26 witnesses, a 2011 Ontario environmental review tribunal decision acknowledged IWTs can harm human health:

> *This case has successfully shown that the debate should not be simplified to one about whether wind turbines can cause harm to humans. The evidence presented to the Tribunal demonstrates that they can, if facilities are placed too close to residents. The debate has now evolved to one of degree.*[20]

Indirect effects and annoyance

When assessing the adverse effects of IWTs it is important to consider what constitutes human health. The World Health Organization (WHO) defines health as "a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity."[21]

Despite being widely accepted, the WHO definition of health is frequently overlooked when assessing the health effects of IWTs. Literature reviews commenting on the health effects of IWTs have been produced with varying degrees of completeness, accuracy, and objectivity.[22] Some of these commentators accept the plausibility of the reported IWT health effects and acknowledge that IWT noise and visual effects might cause annoyance, stress, or sleep disturbance, which can have other consequences. However, these IWT health effects are often discounted because "direct

pathological effects" or a "direct causal link" have not been established. In 2010, the Ontario Chief Medical Officer of Health released *The Potential Health Impact of Wind Turbines,* which acknowledged that some people living near wind turbines report symptoms such as dizziness, headaches, and sleep disturbance but concluded "the scientific evidence available to date does not demonstrate a direct causal link between wind turbine noise and adverse health effects."[23] The lead author of the report,[23] Dr Gloria Rachamin, acknowledged under oath that the literature review looked only at direct links to human health.[24]

Focusing on "direct" causal links limits the discussion to a small slice of the potential health effects of IWTs. The 2011 environmental review tribunal decision found that *serious harm to human health* includes "indirect impacts (e.g., a person being exposed to noise and then exhibiting stress and developing other related symptoms)."[20]

According to the night noise guidelines for Europe:

> *Physiological experiments on humans have shown that noise of a moderate level acts via an indirect pathway and has health outcomes similar to those caused by high noise exposures on the direct pathway. The indirect pathway starts with noise-induced disturbances of activities such as communication or sleep.*[25]

Pierpont documented symptoms reported by individuals exposed to wind turbines, which include sleep disturbance, headache, tinnitus, ear pressure, dizziness, vertigo, nausea, visual blurring, tachycardia, irritability, problems with concentration and memory, and panic episodes associated with sensations of internal pulsation or quivering when awake or asleep.[13] The American Wind Energy Association and the Canadian Wind Energy Association convened a panel literature review that determined these symptoms are the "well-known stress effects of exposure to noise," or in other words, are "a subset of annoyance reactions."[26]

Noise-induced annoyance is acknowledged to be an adverse health effect.[27–30] Chronic severe noise annoyance should be classified as a serious health risk.[31] According to the WHO guidelines for community noise, "[t]he capacity of a noise to induce annoyance depends upon many of its physical characteristics, including its sound pressure level and spectral characteristics, as well as the variations of these properties over time."[32] Industrial wind turbine noise is perceived to be more annoying than transportation noise or industrial noise at comparable sound pressure levels.[33] Industrial wind turbine amplitude modulation,[34] audible low frequency noise,[35] tonal noise, infrasound,[36] and lack of nighttime abatement have been identified as plausible noise characteristics that could cause annoyance and other health effects.

Health effects in Ontario expected

Evidence-based health studies were not conducted to determine adequate setbacks and noise levels for the siting of IWTs before the implementation of the Ontario renewable energy policy. In addition, provision for vigilance monitoring was not made. It is now clear that the regulations are not adequate to protect the health of all exposed individuals.

A 2010 report commissioned by the Ontario Ministry of the Environment concludes:

> *The audible sound from wind turbines, at the levels experienced at typical receptor distances in Ontario, is nonetheless expected to result in a non-trivial percentage of persons being highly annoyed .... [R]esearch has shown that annoyance associated with sound from wind turbines can be expected to contribute to stress related health impacts in some persons.*[37]

Consequently, physicians will likely be presented with patients reporting health effects.

Family physicians should be aware that patients reporting adverse effects from IWTs might experience symptoms that are intense and pervasive and that they might feel further victimized by a lack of care-giver understanding. Those adversely affected by IWTs might have already pursued other avenues to mitigate the health effects with little or no success. It will be important to identify the possibility of exposure to IWTs in patients presenting with appropriate clinical symptoms.[38]

Conclusion

Industrial wind turbines can harm human health if sited too close to residents. Harm can be avoided if IWTs are situated at an appropriate distance from humans. Owing to the lack of adequately protective siting guidelines, people exposed to IWTs can be expected to present to their family physicians in increasing numbers. The documented symptoms are usually stress disorder–type diseases acting via indirect pathways and can represent serious harm to human health. Family physicians are in a position to effectively recognize the ailments and provide an empathetic response. In addition, their contributions to clinical studies are urgently needed to clarify the relationship between IWT exposure and human health and to inform regulations that will protect physical, mental, and social well-being.

Footnotes

This article has been peer reviewed.

La traduction en français de cet article se trouve à **www.cfp.ca** dans la table des matières du numéro de **mai 2013** à la page **e218**.

Competing interests

Dr Jeffery, Ms Krogh, and **Mr Horner** are on the Board of Directors for the Society for Wind Vigilance, an international federation of physicians, acousticians, engineers, and other professionals who share scientific research on the topic of health and wind turbines.

The opinions expressed in commentaries are those of the authors. Publication does not imply endorsement by the College of Family Physicians of Canada.

References

1. Havas M, Colling D. Wind turbines make waves: why some residents near wind turbines become ill. Bull Sci Technol Soc. 2011;31(5):414–26. [Google Scholar]

2. Government of Ontario [website] Chapter 12. An act to enact the Green Energy Act, 2009 and to build a green economy, to repeal the Energy Conservation Leadership Act, 2006 and the Energy Efficiency Act and to amend other statutes. Toronto, ON: Government of Ontario; 2009. Available from: www.e-laws.gov.on.ca/html/source/statutes/english/2009/elaws_src_s09012_e.htm# . Accessed 2013 Mar 26. [Google Scholar]

3. Canadian Wind Energy Association [website] Letter to Neil Parish re: sound level limits for wind farms. Ottawa, ON: Canadian Wind Energy Association; 2004. Available from: www.canwea.ca/images/uploads/File/Wind_Energy_Policy/Environmental_Issues/SoundLevels.pdf . Accessed 2013 Mar 26. [Google Scholar]

4. Hornung R. Business of green: wind energy and budget expectations [video] Toronto, ON: Business News Network; 2010. Available from: http://watch.bnn.ca/clip272347 . Accessed 2013 Apr 4. [Google Scholar]

5. Hanning CD, Evans A. Wind turbine noise. BMJ. 2012;344:e1527. doi: 10.1136/bmj.e1527. [DOI] [PubMed] [Google Scholar]

6. Martin C. NIMBY mentality unacceptable when it comes to green-energy projects, McGuinty says. London Free Press. 2009 Feb 12.

7. Schliesmann P. Wind turbine debate swirls. Kingston Whig-Standard. 2010 Jan 2; Available from: www.thewhig.com/ArticleDisplay.aspx?e=2244137&archive=true . Accessed 2013 Mar 26. [Google Scholar]

8. Académie Nationale de Médecine Groupe de Travail . Le retentissement du fonctionnement des éoliennes sur la santé de l'homme. Paris, France: Académie Nationale de Médecine; 2006. Available from: www.academie-medecine.fr/sites_thematiques/EOLIENNES/chouard_rapp_14mars_2006.htm . Accessed 2013 Mar 26. [Google Scholar]

9. Minnesota Department of Health [website] Public health impacts of wind turbines. St Paul, MN: Minnesota Department of Health; 2009. Available from: www.health.state.mn.us/divs/eh/hazardous/topics/windturbines.pdf . Accessed 2013 Mar 26. [Google Scholar]

10. Harry A. Wind turbines, noise and health. Rowe, MA: National Wind Watch; 2007. Available from: http://docs.wind-watch.org/wtnoise_health_2007_a_harry.pdf . Accessed 2013 Mar 26. [Google Scholar]

11. Phipps R, Amati M, McCoard S, Fisher R. Visual and noise effects reported by residents living close to Manawatu wind farms: preliminary survey results. Rowe, MA: National Wind Watch; 2007. Available from: http://docs.wind-watch.org/phipps-visualnoiseeffects.pdf . Accessed 2013 Mar 26. [Google Scholar]

12. Large Wind Turbine Citizens Committee for the Town of Union . Setback recommendations report. Rowe, MA: National Wind Watch; 2008. Available from: http://docs.wind-watch.org/LWTCC-Town-of-Union_FinalReport_01-14-08.pdf . Accessed 2013 Mar 26. [Google Scholar]

13. Pierpont N. Wind turbine syndrome: a report on a natural experiment. Santa Fe, NM: K-Selected Books; 2009. [Google Scholar]

14. Nissenbaum MA, Aramini JJ, Hanning CD. Effects of industrial wind turbine noise on sleep and health. Noise Health. 2012;14(60):237–43. doi: 10.4103/1463-1741.102961. [DOI] [PubMed] [Google Scholar]

15. Thorne B. The problems with "noise numbers" for wind farm noise assessment. Bull Sci Technol Soc. 2011;31(4):262–90. [Google Scholar]

16. Shepherd D, McBride D, Welch D, Dirks KN, Hill EM. Evaluating the impact of wind turbine noise on health-related quality of life. Noise Health. 2011;13(54):333–9. doi: 10.4103/1463-1741.85502. [DOI] [PubMed] [Google Scholar]

17. Brown County board of health resolution requesting emergency state aid for families suffering around industrial wind turbines. Rowe, MA: National Wind Watch; 2012. Available from: http://docs.wind-watch.org/Brown%20County%20Board%20of%20Health%20Resolution%20011012.pdf . Accessed 2013 Mar 28. [Google Scholar]

18. Krogh CME, Gillis L, Kouwen N, Aramini J. WindVOiCe, a self-reporting survey: adverse health effects, industrial wind turbines, and the need for vigilance monitoring. Bull Sci Technol Soc. 2011;31(4):334–45. [Google Scholar]

19. Krogh CME. Industrial wind turbine development and loss of social justice? Bull Sci Technol Soc. 2011;31(4):321–33. [Google Scholar]

20. Erickson v. Director, Ministry of the Environment. 2011. Environmental Review Tribunal Nos. 10-121 and 10-122. Available from: www.ert.gov.on.ca/files/201108/00000300-AKT5757C7CO026-BHH51C7A7SO026.pdf . Accessed 2013 Mar 28.

21. World Health Organization . Preamble to the Constitution of the World Health Organization. Geneva, Switz: World Health Organization; 1948. Definition of health. Available from: www.who.int/about/definition/en/print.html . Accessed 2013 Mar 28. [Google Scholar]

22. Horner B, Jeffery RD, Krogh CME. Literature reviews on wind turbines and health: are they enough? Bull Sci Technol Soc. 2011;31(5):399–413. [Google Scholar]

23. Chief Medical Officer of Health . The potential health impact of wind turbines. Toronto, ON: Ministry of Health and Long-Term Care; 2010. Available from: http://health.gov.on.ca/en/common/ministry/publications/reports/wind_turbine/wind_turbine.pdf . Accessed 2013 Mar 27. [Google Scholar]

24. Erickson v. Director, Ministry of the Environment. Environmental Review Tribunal Nos. 10-121 and 10-122. Transcript of Dr G. Rachamin. 2011 Mar 4.

25. World Health Organization Europe . Night noise guidelines for Europe. Copenhagen, Denmark: World Health Organization Europe; 2009. Available from: www.euro.who.int/__data/assets/pdf_file/0017/43316/E92845.pdf . Accessed 2013 Mar 27. [Google Scholar]

26. Colby WD, Dobie R, Leventhall G, Lipscomb DM, McCunney RJ, Seilo MT, et al. Wind turbine sound and health effects. An expert panel review. Washington, DC: American Wind Energy Association, Canadian Wind Energy Association; 2009. Available from: www.canwea.ca/pdf/talkwind/Wind_Turbine_Sound_and_Health_Effects.pdf . Accessed 2013 Mar 27. [Google Scholar]

27. Health Canada [website] Community noise annoyance. Ottawa, ON: Health Canada; 2005. Available from: www.hc-sc.gc.ca/hl-vs/iyh-vsv/life-vie/community-urbain-eng.php . Accessed 2013 Mar 27. [Google Scholar]

28. Suter AH. Noise and its effects. Washington, DC: Administrative Conference of the United States; 1991. Available from: www.nonoise.org/library/suter/suter.htm . Accessed 2013 Mar 27. [Google Scholar]

29. Michaud DS, Keith SE, McMurchy D. Noise annoyance in Canada. Noise Health. 2005;7(27):39–47. doi: 10.4103/1463-1741.31634. [DOI] [PubMed] [Google Scholar]

30. Pedersen E, Persson Waye K. Wind turbine noise, annoyance and self-reported health and well-being in different living environments. Occup Environ Med. 2007;64(7):480–6. doi: 10.1136/oem.2006.031039. Epub 2007 Mar 1. [DOI] [PMC free article] [PubMed] [Google Scholar]

31. Maschke C, Niemann A. Health effects of annoyance induced by neighbour noise. Noise Control Eng J. 2007;55(3):348–56. [Google Scholar]

32. Berglund B, Lindvall T, Schwela DH, editors. Guidelines for community noise. Geneva, Switz: World Health Organization; 1999. [Google Scholar]

33. Pedersen E, van den Berg F, Bakker R, Bouma J. Response to noise from modern wind farms in the Netherlands. J Acoust Soc Am. 2009;126(2):634–43. doi: 10.1121/1.3160293. [DOI] [PubMed] [Google Scholar]

34. Leventhall G. Infrasound from wind turbines—fact, fiction or deception. Can Acoust. 2006;34(2):29–36. [Google Scholar]

35. Møller H, Pedersen CS. Low-frequency noise from large wind turbines. J Acoust Soc Am. 2011;129(6):3727–44. doi: 10.1121/1.3543957. [DOI] [PubMed] [Google Scholar]

36. Salt AN, Kaltenbach JA. Infrasound from wind turbines could affect humans. Bull Sci Technol Soc. 2011;31(4):296–302. [Google Scholar]

37. Howe Gastmeier Chapnik Limited . Low frequency noise and infrasound associated with wind turbine generator systems. A literature review. Toronto, ON: Ontario Ministry of the Environment; 2010. Available from: www.ene.gov.on.ca/stdprodconsume/groups/lr/@ene/@resources/documents/resource/stdprod_092086.pdf . Accessed 2013 Mar 27. [Google Scholar]

38. McMurtry RY. Toward a case definition of adverse health effects in the environs of industrial wind turbines: facilitating a clinical diagnosis. Bull Sci Technol Soc. 2011;31(4):316–20. [Google Scholar]

From Carol Black, Citizen of Whitman County

April 28, 2025

Whitman County Commissioners
Whitman County Planning Commission
Whitman County Planner

Dear Commissioners, Planning Commission members, and County Planner:

I have significant concerns about several county-referenced documents posted on the Planning Department website. Some have been touted as important to the decision-making by county officials. Certain documents should be removed since they are inappropriate, outdated, or a process study. Below, I describe concerns and findings and point out documents that should be reviewed and addressed.

Three articles by **American Clean Power** (ACP) that are posted to the website are inappropriate and should be removed. They are documents written by industry advocacy and are not peer-reviewed. It is very important to note that **American Clean Power** is a tax-exempt nonprofit with the goal of Community Improvement, Capacity Building, and Promotion of Business;" thus, advocacy. Their 2023 Form 990 reported that 10.5% of the revenue pays the salaries of their administrative team (source: ProPublica nonprofit explorer).

- CEO Jason Grumet - $1,213,594
- Strategy Officer - $1,119,388
- Chief Advocacy - $1,043,69

The following three documents are outdated. As I noted in my earlier correspondence with you, the turbines being considered for Harvest Hills and other new installations will be much taller and create specific issues that older publications do not address. Referencing data from studies conducted on much older and shorter turbines is not comparable to the newest, taller ones.

- 2011 – 14 years out of date – **Canada Wind Turbine Noise Study -** not peer reviewed and the most important variable that characterizes the wind turbines referenced in the study was not given.

- 2009 – 26 years out of date. No reference to wind turbine heights that correspond to the data collected. Note: the data shows impacts on residences within one-mile. - **Ernest Orlando Lawrence BNL - Impact of Wind Power Projects on Residential Property Values.**

- 2009 – 26 years out of date. No reference to wind turbine heights that correspond to the data collected. **Mark Bastasch CH2M Hill - Memorandum on Noise 2009-09-10.** Note: the conclusion notes the misuse of the term infrasound when sound annoyances are from the "swish," which they note needs "to be focused on in order to reduce it and obtain a proper estimate of its effects. It will then be the responsibility of legislators to fix the criterion levels, However, although the needs of sensitive persons may influence decisions, limits are not normally set to satisfy the most sensitive."

This article is about "process" and does not report on impacts; thus it is not useful for review by interested parties. Its target audience is Humanities & Social Sciences Communications **Mihai Andrei - Wind Turbine Noise Studies 2025-03-12** – Science News. However, I give them full credit for characterizing the turbines that were affiliated with the study. Their findings:

- "we are uncertain whether we would observe no adverse effects if participants were exposed to noise longer, for example, several hours."

I-29

- "our goal was to investigate the direct impact of wind turbine noise on the dynamics of mechanisms controlling cognitive processes."
- This is a pilot study that evaluated a measurement process and not the overall effect. 2MW wind turbine, young adults, 450 foot turbine/blade height, single experiment, very short-term exposure - not long-term exposure, 1 of 15 rated annoyance high (7%), note further research is needed to confirm and address duration.

Finally, this article supports my contention that the "precautionary principle" is needed to protect from the unknown and yet-to-be-determined effects of the newer, taller turbines. *JOEM Nov 2014 – literature review.* Again, it lacks references that characterize the wind turbines associated with the research. **Wind Turbines and Health - A Critical Review of the Scientific Literature (PDF**. Their final result:

- "Given the coarseness of measures used in many studies, the magnitude of these findings are likely attenuated and underestimate the effect of annoyance on QOL. Visual effect increases annoyance beyond sound exposure and noise sensitivity, but at present there is insufficient research to conclude that visual effect operates separately from noise sensitivity because the two variables are correlated."

There is no reference date to the presentation, **Overview of Commercial Wind Ordinance.** The document notes that Whitman County started its wind ordinance in 2009 using Adams County as its template. It references a setback from non-participating occupied structures of **five times the height of the turbine, measured to the full extent of the rotor** (not the same as the current code). Additionally, it references two lawsuits filed based on:

- low frequency noise emissions from the turbines;
- setbacks from turbines to occupied structures; the measurement scale by which noise from turbines is determined;
- despoiling the views on the Palouse with turbines;
- insufficient protection in the code for birds and bats; and
- the lack of provisions for a technical advisory committee.

Lastly, listed below are two articles you may review and consider for posting to the County Planning Division website. I submitted these recently in my correspondence.

- **Science Direct.** February 2024 Volume 185. Commercial wind turbines and residential home values: New evidence from the universe of land-based wind projects in the United States. Eric J. Brunner, Ben Hoen, Joe Rand , David Schwegman https://www.sciencedirect.com/science/article/pii/S0301421523004226

- **Proceeding of the National Academy of Sciences - PNAS.** March 18, 2024. The visual effect of wind turbines on property values is small and diminishing in space and time. Wei Guo, Leonie Wenz and Maximilian Auffhammer https://www.pnas.org/doi/10.1073/pnas.2309372121

Respectfully,

Carol Black

Canadian Journal of Rural Medicine
CSRM CMR
Journal canadien de la médecine rurale

Industrial wind turbines and adverse health effects

Roy D. Jeffery, MD, CCFP, FCFP
Manitoulin Island, Ont.

Carmen M.E. Krogh, BScPharm
Brett Horner, BA, CMA
Killaloe, Ont.

Correspondence to:
Roy Jeffery;
jeffery_07@sympatico.ca

This article has been peer reviewed.

Introduction: Some people living in the environs of industrial wind turbines (IWTs) report experiencing adverse health and socioeconomic effects. This review considers the hypothesis that annoyance from audible IWTs is the cause of these adverse health effects.
Methods: We searched PubMed and Google Scholar for articles published since 2000 that included the terms "wind turbine health," "wind turbine infrasound," "wind turbine annoyance," "noise annoyance" or "low frequency noise" in the title or abstract.
Results: Industrial wind turbines produce sound that is perceived to be more annoying than other sources of sound. Reported effects from exposure to IWTs are consistent with well-known stress effects from persistent unwanted sound.
Conclusion: If placed too close to residents, IWTs can negatively affect the physical, mental and social well-being of people. There is sufficient evidence to support the conclusion that noise from audible IWTs is a potential cause of health effects. Inaudible low-frequency noise and infrasound from IWTs cannot be ruled out as plausible causes of health effects.

Introduction : Des gens qui habitent à proximité des éoliennes industrielles affirment subir des effets préjudiciables pour leur santé et leur situation socio-économique. La présente analyse étudie l'hypothèse selon laquelle le désagrément causé par le bruit des éoliennes serait à l'origine de ces effets néfastes pour la santé.
Méthodes : Nous avons cherché dans PubMed et Google Scholar des articles publiés depuis 2000 et contenant les expressions « wind turbine health », « wind turbine infrasound », « wind turbine annoyance », « noise annoyance » ou « low frequency noise » dans le titre ou le résumé.
Résultats : Les éoliennes industrielles produisent un son qui est perçu comme étant plus désagréable que d'autres sources de bruit. Les effets signalés de l'exposition aux éoliennes industrielles correspondent à des effets de stress bien connus causés par des sons persistants non voulus.
Conclusion : Si elles sont situées trop près des habitations, les éoliennes industrielles peuvent avoir des effets préjudiciables pour le bien-être physique, mental et social des gens. Il existe suffisamment de preuves pour conclure que le bruit audible des éoliennes industrielles est une cause possible d'effets sur la santé. En outre, on ne peut écarter comme cause plausible d'effets sur la santé les sons de basse fréquence et les infrasons produits par ces éoliennes.

Noise

rural medicine impacts

INTRODUCTION

Some people living in the environs of wind energy infrastructure experience negative health effects. Reported effects include annoyance, sleep disturbance, stress-related health impacts and reduced quality of life.[1–12] In some cases, Canadian families have effectively abandoned their homes, been billeted by wind energy developers or negotiated financial agreements with developers.[13]

A 2009 case series by Pierpont[6] included Canadian participants and

I-30

documented symptoms reported by people exposed to industrial wind turbines (IWTs). Documented effects included sleep disturbance, headache, tinnitus, ear pressure, dizziness, vertigo, nausea, visual blurring, tachycardia, irritability, problems with concentration and memory, and panic episodes associated with sensations of internal pulsation or quivering when awake or asleep. Pierpont called the symptoms "wind turbine syndrome" and proposed the cause to be low-frequency noise (LFN) from IWTs or vibration stimulation of receptors of the human balance system.[6]

The American Wind Energy Association and Canadian Wind Energy Association sponsored a literature review to consider the existing literature on wind turbine noise and health.[14] Colby and colleagues[14] determined that "'wind turbine syndrome' symptoms are not new and have been published previously in the context of 'annoyance'" and are the "well-known stress effects of exposure to noise ...."

In this review, we consider the hypothesis of Colby and colleagues that the health effects from IWTs are the result of annoyance from the noise of audible IWTs.[14] We also discuss emerging knowledge on the effects of inaudible LFN and infrasound.

METHODS

We searched PubMed and Google Scholar for articles published since 2000 that included the terms "wind turbine health," "wind turbine infrasound," "wind turbine annoyance," "noise annoyance" or "low frequency noise" in the title or abstract.

We also considered additional documents received following author correspondence. Additional documents included, but were not limited to, government documents obtained by freedom-of-information requests and literature reviews.

RESULTS

Definitions: noise and health

The World Health Organization (WHO) defines noise as "unwanted sound."[15] Noise of a moderate level acts via an indirect pathway and can have health outcomes similar to those caused by high noise exposures on the direct pathway.[16] The main health risks of noise, identified by WHO, include the following: pain and hearing fatigue, hearing impairment, tinnitus, annoyance, interferences with social behaviour, interference with speech communication, sleep disturbance, cardiovascular effects, hormonal responses, and reduced performance at work and school.[17]

Canada supports the definition of health established in the 1948 WHO constitution: "Health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity."[18] Michaud and colleagues state that "[u]nder this broad definition, noise-induced annoyance is an adverse health effect."[19]

In a document about the process of environmental assessments, Health Canada states that it "considers the following noise-induced endpoints as health effects: noise-induced hearing loss, sleep disturbance, interference with speech comprehension, complaints, and change in percent highly annoyed (%HA)."[20]

Effects of noise-induced annoyance

In a report on the health effects of wind turbines, the Minnesota Department of Health stated that "[t]he most common complaint in various studies of wind turbine effects on people is annoyance or an impact on quality of life."[21]

Annoyance has been defined as "... a feeling of displeasure associated with any agent or condition, known or believed by an individual or group to adversely affect them ...."[15] A causal chain exists between strong annoyance and increased morbidity,[22] and chronically strong annoyance must be classified as a serious human health risk.[23]

Symptoms associated with annoyance include stress, sleep disturbance, headaches, difficulty concentrating, irritability, fatigue, dizziness or vertigo, tinnitus, anxiety, heart ailments and palpitation. [24–26] In western European countries, noise-induced sleep disturbance and annoyance are estimated to account for 903 000 and 587 000 disability-adjusted life years, respectively.[27]

Industrial wind turbines can be harmful to health

Literature reviews have commented on the health effects of IWTs. Systematic audits of reviews reveal that some works contain errors of omission or commission.[28] One recurring error of omission is the failure to disclose that IWT noise acting via the indirect pathway can cause health effects.

A 2011 Ontario Environmental Review Tribunal considered evidence and testimony under oath and found that IWTs can be harmful to health if they are placed too close to residents.[29] The tribunal decision also found that

"serious harm to human health" includes ... indirect impacts (e.g., a person being exposed to noise and then exhibiting stress and developing other related symptoms). This approach is consistent with both the WHO definition of health and Canadian jurisprudence on the topic.[29]

Plausible causes of IWT-related health effects

Industrial wind turbines and related infrastructure can have a negative impact on living environments. Noise, visual impacts, stray voltage and socio-economic impacts related to IWTs are identified as plausible causes of adverse effects.

Electromagnetic waves in the form of poor power quality and ground current can adversely affect people who are electrically hypersensitive. Poor power quality and ground current have been documented at homes in proximity to Ontario IWTs.[30]

The National Research Council reports that

... to the extent that wind-energy projects create negative impacts on human health and well-being, the impacts are experienced mainly by people living near wind turbines who are affected by noise and shadow flicker.[31]

The blades of IWTs produce unavoidable shadow flicker bright enough to pass through closed eyelids, and moving shadows cast by the blades on windows can affect illumination inside buildings.[32] The Danish Energy Agency classifies shadow flicker from IWTs experienced by residents as a "nuisance."[33]

People exposed to shadow flicker from IWTs report negative effects to their health and well-being.[7] Currently, most jurisdictions in Canada do not have regulations that prevent negative effects from visual burdens caused by IWTs.

Noise from IWTs is more annoying than other noises

The Canadian Wind Energy Association suggests that modern wind turbines are not noisy.[34] European peer-reviewed studies consistently document that IWTs produce sound that is perceived to be more annoying than transportation or industrial noise at comparable sound pressure levels.[1,5]

In a 2006 report, the Académie nationale de médecine working group noted that IWT noise was the most frequent complaint.[35] The report described IWT noise as piercing, preoccupying and continually surprising because it is irregular in intensity, which distracts attention or disturbs rest. Industrial wind turbines have been blamed for other problems experienced by people living nearby, including subjective (headaches, fatigue, temporary feelings of dizziness and nausea), and objective (vomiting, insomnia and palpitations) manifestations.[35]

Health effects expected in rural Canada

Industrial wind turbines are sited in proximity to Canadian homes to enable access to transmission infrastructure.[36] Internal correspondence from the Ontario Ministry of the Environment, obtained through a freedom-of-information request, states, "It appears compliance with the minimum setbacks and the noise study approach currently being used to approve the siting of WTGs [wind turbine generators] will result or likely result in adverse effects ...."[37]

A report commissioned by the Ontario Ministry of the Environment concluded that the sound from wind turbines, at the levels experienced at typical receptor distances in Ontario, was

... expected to result in a non-trivial percentage of persons being highly annoyed ... research has shown that annoyance associated with sound from wind turbines can be expected to contribute to stress related health impacts in some persons.[38]

Noise annoyance in rural Canada is extremely low.[39,40] Canadian communities with populations of less than 5000 report that about 70% are "not at all annoyed" by noise outside their home.[19]

Health Canada's examination of the scientific literature on noise from IWTs determined the health effect "conclusively demonstrated" from exposure to wind turbine noise is an increase of self-reported general annoyance and complaints (i.e., headaches, nausea, tinnitus and vertigo).[41] Members of Health Canada's Consumer and Clinical Radiation Protection Bureau propose a sound limit of 45 dBA for IWTs and predict an increase in the percentage of Canadians highly annoyed by noise from IWTs.[42–44]

A noise immission level of 45 dBA from IWTs can be expected to result in "... less than 14% of the exposed population to be highly annoyed indoors by wind turbines and less than 29% to be highly annoyed outdoors."[45]

There is a greater expectation for, and value placed on, "peace and quiet" in quiet rural settings.[44,46] Such settings in Ontario can have ambient sound levels below 30 dBA.[37] Annoyance from IWT noise starts at dBA sound pressure levels in the low 30s and rises sharply at 35 dBA.[1,3,5] Research suggests that IWT noise limits should be set at 32 dBA outside residences.[9] A 2010 memorandum of the Ontario Ministry of the Environment recommended

that IWT "... setback distances should be calculated using a sound level limit of 30 to 32 dBA at the receptor ...."[37] Ontario guidelines for IWT noise currently permit up to 51 dBA.[47]

A health survey of people exposed to IWTs in Ontario reported altered quality of life, sleep disturbance, excessive tiredness, headaches, stress and distress.[7] Predicted probability of health effects diminished with increased distance between the IWT and the participant's property.[7] Nissenbaum and colleagues[12] also documented a reduction of effects with increased distances of IWTs from residences. These findings are consistent with the physics of sound decay through absorption by the ground and atmosphere.

Negative attitudes toward IWTs have been suggested as a cause of annoyance complaints.[14,48] However, researchers have found that IWTs were initially welcomed into the communities for their perceived environmental[8] or economic[12] benefits. As Krogh states, "[t]he reported adverse impacts were unexpected."[13]

Characteristics of IWT noise

The sound of IWTs is very easily perceived[49] and is difficult to mask.[1,5] The characteristics of IWT noise that are identified as plausible causes for reported health effects include amplitude modulation,[50] audible low-frequency noise (LFN),[21] infrasound,[61] tonal noise, impulse noise and night-time noise.[5]

Amplitude modulation and impulse noise

Modern IWTs routinely produce audible amplitude modulation. Leventhall[50] reports that "[a] time-varying sound is more annoying than a steady sound of the same average level and this is accounted for by reducing the permitted level of wind turbine noise." Pedersen and van den Berg[52] state that "[f]rom various studies it follows that this modulation is equivalent in annoyance to the un-modulated sound at an approximately 5 dB higher level." Ontario noise guidelines require a 5 dBA adjustment for industrial noise that has amplitude modulation[53] but not for IWTs.[47] Industrial wind turbines also produce impulsive sound, which can be unexpected and disturbing to residents.[9,54]

Audible LFN

Modern IWTs routinely produce audible LFN.[38] As IWTs have increased in size, so has the LFN part of the sound spectrum. For modern IWTs, it is

> ... beyond any doubt that the low-frequency part of the spectrum plays an important role in the noise .... It must be anticipated that the problems with low-frequency noise will increase with even larger turbines.[55]

Annoyance from audible LFN is acknowledged to be more severe in general.[15] Low-frequency noise does not need to be considered loud for it to cause annoyance and irritation.[25] It causes immense suffering to those who are sensitive to it,[24] and chronic psychophysiological damage may result from long-term exposure to low-level LFN.[56]

Infrasound and inaudible LFN

Industrial wind turbines also produce infrasound and/or inaudible LFN. There is debate about the impact from these low frequencies of noise.[38] It has been suggested that these low frequencies are not sufficient to result in negative effects.[14,48,50] However, Farboud and colleagues[57] state that "... there is an increasing body of evidence suggesting that infrasound and low frequency noise have physiological effects on the ear." Salt and Kaltenbach[58] report, "[b]ased on well-documented knowledge of the physiology of the ear and its connections to the brain, it is scientifically possible that infrasound from wind turbines could affect people living nearby."

In a 1990 NASA technical paper, Hubbard and Shepphard[59] report that

> [p]eople who are exposed to wind turbine noise inside buildings experience a much different acoustic environment than do those outside. ... They may actually be more disturbed by the noise inside their homes than they would be outside. ... One of the common ways that a person might sense the noise-induced excitation of a house is through structural vibrations. This mode of observation is particularly significant at low frequencies, below the threshold of normal hearing.[59]

Low-frequency noise produced by some IWT projects in Ontario has been found to be inaudible outside the home but audible inside and "... quite annoying to the occupants."[37]

Low-frequency noise from IWTs has resulted in reported annoyance, sleep deprivation and uninhabitable living conditions.[37] To escape the noise, some Ontarians report sleeping in vehicles, tents, trailers, basements lined with mattresses, garages, and at the homes of relatives or friends.[13] Ontario does not have "... measurement procedures or criteria for addressing indoor noise intrusions due to wind turbines ...."[38]

In 2012, a board of health resolution concerning an IWT project in Brown County, Wisconsin, requested

> ... temporary emergency financial relocation assistance from the State of Wisconsin for those Brown County families that are suffering adverse health effects and undue hardships caused by the irresponsible placement of industrial wind turbines around their homes and property.[60]

A 2012 cooperative measurement survey and analysis of LFN and infrasound at the location concluded,

> [t]he four investigating firms are of the opinion that enough evidence and hypotheses have been given herein to classify LFN and infrasound as a serious issue, possibly affecting the future of the industry. It should be addressed beyond the present practice of showing that wind turbine levels are magnitudes below the threshold of hearing at low frequencies.[61]

In 2013, research funded by the Ontario Ministry of the Environment indicated a statistically significant relation between residents' distance from the turbine and the symptoms of disturbed sleep, vertigo and tinnitus, and recommended that future research focus on the effects of wind turbine noise on sleep disturbance and symptoms of inner ear problems.[62]

CONCLUSION

Health is one of the fundamental rights of every human being. Some people exposed to IWTs experience negative effects to their physical, mental and social well-being. There is sufficient evidence to support the hypothesis of Colby and colleagues[14] that documented symptoms can result from annoyance to audible IWTs. Amplitude modulation of IWTs, audible LFN, and tonal, impulse and nighttime noise can contribute to annoyance and other effects on health. In addition, there is emerging evidence that suggests inaudible LFN or infrasound from IWTs may result in negative health effects.

Further research is required to clarify the exact role that sound characteristics, visual impacts, stray voltage and socioeconomic impacts of IWTs may have on human health. As more IWTs are installed, rural physicians are likely to be presented with increasing numbers of patients who are adversely affected. Based on current knowledge, we expect that, at typical setback distances and sound pressure levels of IWTs in Ontario, a nontrivial percentage of exposed people will be adversely affected. "Trade-offs" of health for perceived benefit in alternate forms of energy can be prevented if setback distances and noise limits are developed using established noise management techniques. In addition to providing care for affected patients, rural physicians have a responsibility to advance understanding and to help inform IWT regulations that will protect the physical, mental and social well-being of patients.

Competing interests: None declared.

REFERENCES

1. Pedersen E, Persson KW. Perception and annoyance due to wind turbine noise — a dose response relationship. *J Acoust Soc Am* 2004; 116:3460-70.
2. Harry A. *Wind turbines, noise and health.* Hawley (MA): National Wind Watch; 2007. Available: http://docs.wind-watch.org/wtnoise_health_2007_a_harry.pdf (accessed 2013 Dec. 8).
3. Pedersen E, Persson Waye K. Wind turbine noise, annoyance and self-reported health and well being in different living environments. *Occup Environ Med* 2007;64:480-6.
4. Phipps R, Amati M, McCoard S, et al. *Visual and noise effects reported by residents living close to Manawatu wind farms: preliminary survey results.* Hawley (MA): National Wind Watch; 2008. Available: www.wind-watch.org/documents/visual-and-noise-effects-reported-by-residents-living-close-to-manawatu-wind-farms-preliminary-survey-results/ (accessed 2013 Dec. 8).
5. Pedersen E, Bakker R, Bouma J, et al. Response to noise from modern wind farms in the Netherlands. *J Acoust Soc Am* 2009;126:634-43.
6. Pierpont N. *Wind turbine syndrome: a report on a natural experiment.* Santa Fe (NM): K-Selected Books; 2009.
7. Krogh C, Gillis L, Kouwen N, et al. WindVOiCe, a self-reporting survey: adverse health effects, industrial wind turbines, and the need for vigilance monitoring. *Bull Sci Technol Soc* 2011;31:334-45.
8. Shepherd D, McBride D, Welch D, et al. Evaluating the impact of wind turbine noise on health-related quality of life. *Noise Health* 2011;13:333-9.
9. Thorne B. The problems with "noise numbers" for wind farm noise assessment. *Bull Sci Technol Soc* 2011;31:262-90.
10. Rand R, Ambrose S, Krogh C. Wind turbine acoustic investigation: infrasound and low-frequency noise — a case study. *Bull Sci Technol Soc* 2012;32:128-41.
11. Falmouth Board of Health. Falmouth Health Department requests state assessment of turbine health impacts [letter to Massachusetts Department of Public Health]. June 11, 2012. Available: www.windaction.org/posts/34304-falmouth-health-department-requests-state-assessment-of-turbine-health-impacts#.Up4xXNJDvYw (accessed 2013 Dec. 8).
12. Nissenbaum M, Aramini J, Hanning C. Effects of industrial wind turbine noise on sleep and health. *Noise Health* 2012;14:237-43.
13. Krogh C. Industrial wind turbine development and loss of social justice? *Bull Sci Technol Soc* 2011;31:321-33.
14. Colby WD, Dobie R, Leventhall G, et al. *Wind turbine sound and health effects: an expert panel review.* Washington (DC): American Wind Energy Association and Canadian Wind Energy Association; 2009. Available: www.canwea.ca/pdf/talkwind/Wind_Turbine_Sound_and_Health_Effects.pdf (accessed 2013 Dec. 8).
15. Berglund B, Lindvall T, Schwela DH. *Guidelines for community noise.* Geneva (Switzerland): World Health Organization; 1999.
16. *Night noise guidelines for Europe.* Geneva (Switzerland): World Health Organization; 2009. Available: www.euro.who.int/__data/assets/pdf_file/0017/43316/E92845.pdf (accessed 2013 Dec. 8).
17. World Health Organization. Noise and health. Available: www.euro.who.int/en/health-topics/environment-and-health/noise (accessed 2009 Mar. 9).

18. Preamble to the Constitution of the World Health Organization as adopted by the International Health Conference, New York, 19–22 June, 1946; signed on 22 July 1946 by the representatives of 61 States (Official Records of the World Health Organization, no. 2, p. 100) and entered into force on 7 April 1948.
19. Michaud DS, Keith SE, McMurchy D. Noise annoyance in Canada. *Noise Health* 2005;7:39-47.
20. *Useful information for environmental assessments.* Ottawa (ON): Health Canada; 2010.
21. *Public health impacts of wind turbines.* St. Paul (MN): Minnesota Department of Health; 2009. Available: www.health.state.mn.us/divs/eh/hazardous/topics/windturbines.pdf (accessed 2013 Dec. 8).
22. Niemann H, Maschke C. *WHO LARES: final report: noise effects and morbidity.* Geneva (Switzerland): World Health Organization; 2004.
23. Maschke C, Niemann A. Health effects of annoyance induced by neighbour noise. *Noise Control Eng J* 2007;55:348-56.
24. Leventhall G, Pelmear P, Benton S. *A review of published research on low frequency noise and its effects.* London (UK): Department for Environment, Food and Rural Affairs; 2003. Contract ref: EPG 1/2/50.
25. DeGagne DC, Lapka SD. Incorporating low frequency noise legislation for the energy industry in Alberta, Canada. *Journal of Low Frequency Noise Vibration and Active Control* 2008;27:105-20.
26. Schust M. Effects of low frequency noise up to 100 Hz. *Noise Health* 2004;6:73-85.
27. *Environmental health inequalities in Europe.* Geneva (Switzerland): World Health Organization; 2012.
28. Horner B, Jeffery R, Krogh C. Literature reviews on wind turbines and health: Are they enough? *Bull Sci Technol Soc* 2011;31:399-413.
29. Erickson v. Director, Ministry of the Environment. Environmental Review Tribunal case nos. 10-121/10-122. Available: www.nrwc.ca/wp-content/uploads/2012/05/00000300-AKT5757C7CO026-BG154ED19RO026.pdf (accessed 2013 Dec. 5).
30. Havas M, Colling D. Wind turbines make waves: why some residents near wind turbines become ill. *Bull Sci Technol Soc* 2011;31:414-26.
31. Committee on Environmental Impacts of Wind Energy Projects, National Research Council. *Environmental impacts of wind-energy projects.* Washington (DC): National Academies Press; 2007.
32. Harding G, Harding P, Wilkins A. Wind turbines, flicker, and photosensitive epilepsy: Characterizing the flashing that may precipitate seizures and optimizing guidelines to prevent them. *Epilepsia* 2008;49:1095-8.
33. *Wind turbines in Denmark.* Copenhagen (Denmark): Danish Energy Agency; 2009.
34. *The sights and sounds of wind.* Ottawa (ON): The Canadian Wind Energy Association. Available: http://grandbend.northlandpower.ca/site/northland_power___grand_bend_wind_farm/assets/pdf/7_visual_and_sound.pdf (accessed 2013 Dec. 8).
35. Chouard CH. *Le retentissement du fonctionnement des éoliennes sur la santé de l'homme.* Paris (France): Académie nationale de médecine; 2006.
36. Hornung R. Business of green: wind energy and budget expectations [interview]. *Business News Network.* 2010 Mar. 4. Available: http://watch.bnn.ca/clip272347 (accessed 2013 Dec. 8).
37. Ontario Ministry of the Environment, internal correspondence. Obtained through freedom of information request. 2011. Date of FOI release: May 30, 2011. File # A-2010-03071.
38. Howe B. *Low frequency noise and infrasound associated with wind turbine generator systems: a literature review.* Ontario Ministry of the Environment RFP no. OSS-078696. Mississauga (ON): Howe Gastmeier Chapnik Limited; 2010.
39. *Health insider: traffic noise outside the home POR-02-65-S.* Rouyn-Noranda (QC): IBM Business Consulting Services; 2002.
40. *2002 Health Insider No. 7. Noise: propriety questions for Health Canada.* Price Waterhouse Consulting; 2002. Contract no. H1011-010139/001/CY.
41. Correspondence from the Honourable Rona Ambrose. Obtained through freedom of information request. June 30, 2009. Date of FOI release: May 30, 2011. File # A-2010-03071.
42. Keith SE, Michaud DS, Bly SHP. A justification for using a 45 dBA sound level criterion for wind turbine projects. N.D. Keith SE, Michaud DS, Bly SHP. *Can Acoust* 2008;36:54.
43. Keith SE, Michaud DS, Bly SHP. A proposal for evaluating the potential health effects of wind turbine noise for projects under the Canadian Environmental Assessment Act. Second International Meeting on Wind Turbine Noise; Lyon (France); Sept. 20–21 2007.
44. Keith SE, Michaud DS, Bly SHP. A proposal for evaluating the potential health effects of wind turbine noise for projects under the Canadian Environmental Assessment Act. *J Low Freq Noise.* 2008;27:253-65.
45. Janssen Sabine A, Vos H, Eisses AR, et al. A comparison between exposure-response relationships for wind turbine annoyance and annoyance due to other noise sources. *J Acoust Soc Am* 2011;130:3746-53.
46. *Quantities and procedures for description and measurement of environmental sound: part 4. Noise assessment and prediction of long-term community response.* (ANSI S12.9-2005/part 4). Washington (DC): American National Standards Institute, Acoustical Society of America; 2005.
47. *Noise guidelines for wind farms: interpretation for applying MOE NPC publications to wind power generation facilities.* Toronto (ON): Ontario Ministry of the Environment; 2008. Available: www.ene.gov.on.ca/stdprodconsume/groups/lr/@ene/@resources/documents/resource/std01_079435.pdf (accessed 2013 Dec. 8).
48. Knopper L, Ollson C. Health effects and wind turbines: a review of the literature. *Environ Health* 2011;10:78.
49. Pedersen E, van den Berg F, Bakker R, et al. Can road traffic mask sound from wind turbines? Response to wind turbine sound at different levels of road traffic sound. *Energy Policy* 2010;38:2520-7.
50. Leventhall G. Infrasound from wind turbines — fact, fiction or deception. *Can Acoust* 2006;34:29-36.
51. Salt AN, Hullar TE. Responses of the ear to low frequency sounds, infrasound and wind turbines. *Hear Res* 2010;268:12-21.
52. Pedersen E, van den Berg F. Why is wind turbine noise poorly masked by road traffic noise? *Proceedings of the InterNoise 2010 Conference;* 2010 June 13–16; Lisbon (Portugal).
53. *Publication NPC-104: sound level adjustments.* Toronto (ON): Ontario Ministry of the Environment.
54. Shepherd D, Billington R. Mitigating the acoustic impacts of modern technologies: acoustic, health, and psychosocial factors informing wind farm placement. *Bull Sci Technol Soc* 2011;31:389.
55. Møller H, Pedersen CS. Low-frequency noise from large wind turbines. *J Acoust Soc Am* 2011;129:3727-44.
56. Leventhall G. Low frequency noise and annoyance. *Noise Health* 2004;6:59-72.
57. Farboud A, Crunkhorn R, Trinidade A. 'Wind turbine syndrome': Fact or fiction? *J Laryngol Otol* 2013;127:222-6.
58. Salt AN, Kaltenbach JA. Infrasound from wind turbines could affect humans. *Bull Sci Technol Soc* 2011;31:296-302.
59. Hubbard HH, Sheppard KP. *Wind turbine acoustics.* NASA Technical Paper 3057, DOE/ NASA/20320-77. NASA; 1990.
60. *Brown County Board of Health resolution requesting emergency state aid for families suffering around industrial wind turbines.* Rowe (MA): National Wind Watch; 2012.
61. Walker B, Hessler G, Hessler D, et al. *A cooperative measurement survey and analysis of low frequency and infrasound at the Shirley Wind Farm in Brown County, Wisconsin.* Report no. 122412-1. Camarillo (CA): Channel Islands Acoustics; 2012.
62. Wind turbine noise, sleep quality, and symptoms of inner ear problems. *Symposia of the Ontario Research Chairs in Public Policy;* 2013 Oct. 17; Toronto (ON).

26th INTERNATIONAL CONGRESS ON SOUND AND VIBRATION
7-11 July 2019 Montreal

INFRASOUND AND LOW FREQUENCY NOISE GUIDELINES: ANTIQUATED AND IRRELEVANT FOR PROTECTING POPULATIONS

Mariana Alves-Pereira
ECEO, Universidade Lusófona, Lisbon, Portugal
email: m.alvespereira@gmail.com

Carmen Krogh
The Society for Wind Vigilance (Not-For-Profit Incorporation) & Magentica Research Group (Not-For-Profit Incorporation), Ontario, Canada
e-mail: carmen.krogh@gmail.com

Huub H. C. Bakker
Massey University, Palmerston North, New Zealand
e-mail: H.H.Bakker@massey.ac.nz

S. Rachel Summers
Massey University, Palmerston North, New Zealand
e-mail: s.r.summers@massey.ac.nz

Bruce I. Rapley
Smart Technologies, Palmerston North, New Zealand
e-mail: Consultant@smart-technologies.co.nz

Infrasound.

Need new data for health

Background: Over the past two decades, the increasing and unregulated production of infrasound and low frequency noise (ILFN, ≤200 Hz) has led to a considerable rise in associated noise complaints and health-related issues. The most recent of such ILFN sources are industrial wind turbines (IWT). Acoustical field-data was collected within a home located in the vicinity of IWT, to which the AUC Rule 012 and its requirements were applied. In Ontario, IWT noise complaints were gathered under the Freedom of Information legislation. **Goal:** To explore the usefulness of current noise control rules when protecting human populations against ILFN generated by IWT.

Keywords: industrial wind turbines, residential exposure, health, dBA, acoustic signatures

I-31

1. Background

The unbridled installation of industrial wind turbines (IWT) in different countries on different continents has brought a *very old problem* [1] to centre stage: the health effects induced by excessive exposure to anthropogenic (i.e., artificially generated, human-made) airborne pressure waves occurring within the lower ranges of the acoustical frequency spectrum (a.k.a. infrasound (<20 Hz) and low frequency noise (≤200 Hz), or, ILFN, given the absence of a more precise nomenclature). The goal of this report is to (yet again) emphasize the long-standing problem of anthropogenic ILFN impacting human health, this time using IWT as a source-example.

2. Industrial wind turbine 'noise' in Canada

2.1 IWT 'noise' complaints in Ontario

The government of Ontario, Canada has a process for reporting environmental pollution that offers a pollution reporting "hotline," managed by the Ministry of Environment, Conservation and Parks (MOECP), and which includes noise pollution complaints [2]. People living in proximity to IWT projects have used this service to submit Incident Reports/Complaints (IR/C) regarding environmental noise and associated adverse health effects. In order to evaluate the effectiveness of this process of reporting IWT 'noise,' government IR/C records were obtained through a request made under the province of Ontario's Freedom of Information legislation [3] by the community group coalition Wind Concerns Ontario [4].

Findings were presented during a citizen appeal of an IWT project held before the Ontario Environmental Review Tribunal [4]. Testimony included factual evidence based on the official government IR/C records submitted by residents living in proximity to operating IWT [5]. The total number of Incidents filed officially with the MOECP between 2006 and the end of 2016 was 4,574. Only 1% of the reports received a "priority" response, another 30% were deemed as "deferred," and records showed that in more than 50% of the Complaints, there was no ministry response [5]. Regarding health effects, notes by the Ministry's Provincial Officers included statements from citizens reporting "headache, sleep deprivation, annoyance, and ringing or pressure sensation in the head and ears" [5]. These health effects were reported many times, and also included children [5].

2.2 Rule 012 for Noise Control in Alberta

In the Province of Alberta, the Utilities Commission has Rule 012 [6] dedicated to *Noise Control* that encompasses "an avenue for the submission of noise complaints relating to a facility and the process for addressing noise complaints" [7]. Rule 012 imposes a limit based on a minimum basic sound level to which various adjustments are made:

Permissible Sound Level	=	Basic sound level	+	Daytime adjustment	+	Class A adjustment	+	Class B Adjustment	+	Class C adjustment

The basic sound level begins at 40 dBA L_{eq} and increases depending on the number of houses nearby and proximity of heavily travelled roads. The Daytime adjustment is an increase of 10 dBA between 7 am and 10 pm. Class A adjustments address seasonal variation and non-representative ambient monitoring. Class B adjustments are made for temporary increases in noise generation. Class C adjustments are made when the ambient wind increases to a level that masks the generated noise. On the matter of low-frequency components, Section 3.2 states: "If available, C-weighted sound pressure level (dBC) minus the A-weighted sound pressure level (dBA) is to be considered in the noise model…to identify the potential for low frequency noise impacts." The procedure then described in

Section 4.5 and Appendix 5 is required only when low frequency noise is identified subsequent to the complaint investigation. Therefore, the difference between the overall C-weighted sound level and the A-weighted sound level must be calculated for all pertinent recordings and the periodograms analysed for sharp peaks in the 20–250-hertz region. Only if both the dBC – dBA difference is greater than 20 dB *and* sharp peaks are identified, is a more comprehensive investigation of ILFN required.

3. IWT in Germany – Case Report

3.1 Background

Beginning in 2014, the Hogeveen family residing in Schleswig-Holstein, Germany, described the symptoms (to the media) that they and their children had been developing after 20 IWT were commissioned within a 2-km radius of their home [8-10]. The children—who exhibited increased aggressiveness and unexplained nosebleeds—were promptly sent to boarding school to avoid further health deterioration. The Hogeveens had to remain in the home since it is also their place of work (sports medicine and physical therapy centre), while persistently enduring dizziness, headaches, sensations of pressure on the chest and lungs, ear-aches, swollen tonsils, and ocular and oral inflammations [8-10]. But, they abandoned their upstairs bedroom and constructed a bunker-bedroom deep in the basement of the home. This has provided some respite, except when winds are easterly. Acoustical recordings were conducted simultaneously in both abandoned and bunker bedrooms, taking wind conditions into account.

3.2 Materials and methods for acoustic capture

Data were captured with a SAM Scribe FS (Full Spectrum) system (Model: Mk1, Atkinson & Rapley, Palmerston North, New Zealand) [11,12]. This two-channel recorder measures at sampling rates up to 44.1 kHz, and delivers data streams via USB to a Windows notebook computer, storing it as uncompressed wav files to hard disk. GPS information is also stored as metadata in the files, and this includes a digital signature. The manufacturer's frequency response curve shows a microphone capsule very close to linear over the 1-1000 Hz range used in this study (0.5-1000 Hz: ± 0.5 dB; 1-10 kHz: ± 2dB; 10-20 kHz: ± 4dB) (custom-made Model No.: EM246ASS'Y, Primo Co, Ltd, Tokyo, Japan) [13]. Acoustic data was processed in Matlab (The MathWorks, USA) using narrow-band filters complying with the ANSI® S1.11-2004 and IEC 61260:1995 standards. All data presented herein were captured a sampling rate of 11.025 kHz and recorded as uncompressed WAV files, including the required reference calibration tone (Type I Calibrator, 1000 Hz/94 dB). Windshields were placed on both microphones during the entire measurement periods. Microphones were attached to tripods at approximately 1.5 m above the ground. The recordings selected for analysis and presentation herein were chosen on their educational value, and are shown in Table 1.

Table 1: Samples selected for analysis and presentation herein.

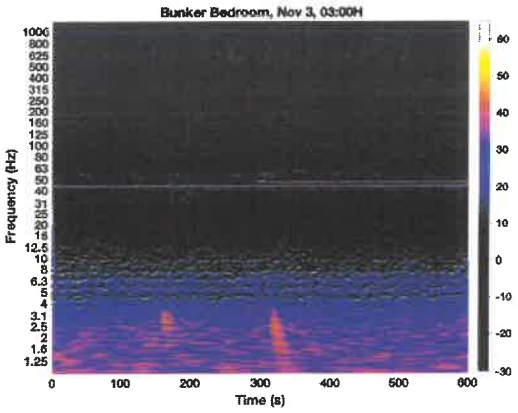
Sample	Date	Time	Wind Speed (m/s)	Wind Direction
Lo wind	03NOV17	03:00	0.9	290°
Hi wind	01NOV17	14:00	7.6	290°

3.3 Abandoned vs. Bunker bedrooms

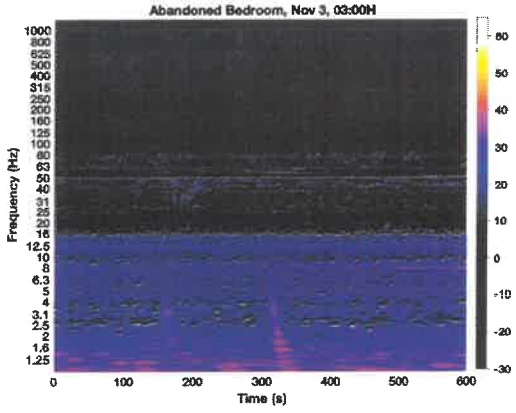
Significant and distinctive differences were found between the two environments that survived changes in wind speed and wind direction. Figure 2A-D compares the sonograms of the simultaneous recordings captured in both locations, under both wind speeds. All disclose some tonal components (horizontal lines) although these appear more prominent in the abandoned bedroom than in the bunker bedroom. The abandoned bedroom discloses larger SPL values between approximately 5-40 Hz in low wind conditions (0.9 m/s, Fig. 2B), and between 6.3-40 Hz in the high-wind conditions (7.6 m/s,

Fig. 2D). Within those frequency bands, distinct peaks at 8 and 12 Hz, as well as a peak at 80 Hz, are present in the abandoned bedroom, but absent from the bunker bedroom. Apart from some wind-gust noise—seen as vertical features broadening and moving to the right with decreasing frequency—the sonograms tend to show that the character of the sound does not change throughout the 10-minute periods and so the periodograms, shown in Figure 3, are representative of the sound over those intervals. (The continuous, 1000-Hz tone seen in the quieter recordings is due to electronic noise within the SAM Scribe Mk1, eliminated in the more recent SAM Scribe models.)

Wind speed 0.9 m/s and westerly wind (290°) on 03 Nov 2017, at 03:00H.

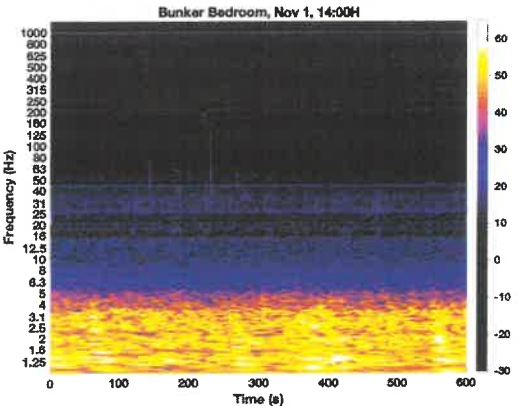


A. Bunker bedroom.

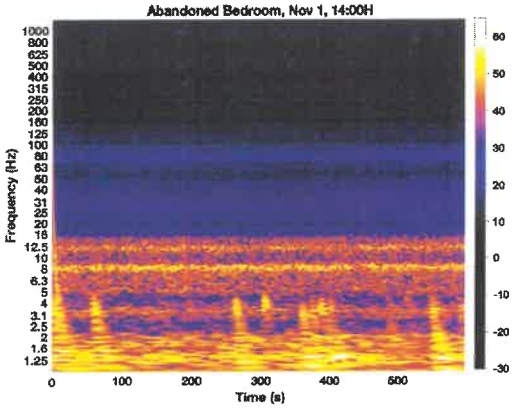


B. Abandoned bedroom.

Wind speed 7.6 m/s and westerly wind (290°) on 01 Nov 2017, at 14:00H.



C. Bunker bedroom.



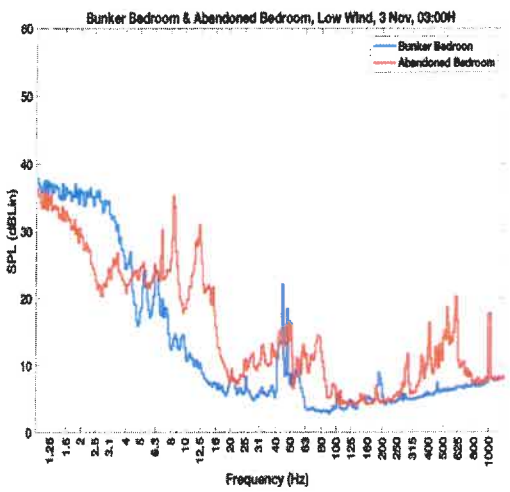
D. Abandoned bedroom.

Figure 2: Sonograms covering a 10-min interval (600 s) and analyzed between 1–1250 Hz. The color-coded bar on the right indicates SPL in dBLin.

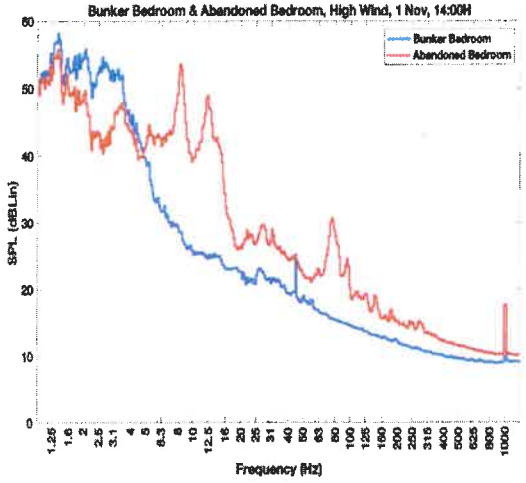
In the abandoned bedroom, the shapes and positions of the peaks at the three frequencies (8, 12 and 80 Hz, Fig. 3) are quite distinct, are clearly identifiable and independent of wind speed. Particularly visible in Fig. 3 is the similarity in the profile, occurring simultaneously in both locations, at the lower limiting frequencies of these measurements, i.e., approximately from 0.1 Hz to 2.5 Hz or to 4.5 Hz. The acoustical events responsible for these readings seem to impact both locations in the same manner, independent of wind conditions. The wavelengths corresponding to the airborne acoustical events at

these frequency values are, approximately, 76 m (4.5 Hz) to 3430 m (at 0.1 Hz). The source of these phenomena remains unclear.

At low wind speed (0.9 m/s), the bunker bedroom displays a continuous tone at approximately 50 Hz. This can be seen as a horizontal line in the sonograms (Fig. 2A and 2C), as peaks in the classical analysis (Fig. 4), and as narrow peaks in the corresponding periodogram (Fig. 3). Usually, these tones are attributed to electrical appliances that may be present in the environment, and that do not vary with wind conditions. This is much less obvious in the abandoned bedroom (Fig. 2B and 2D) since no appliances are currently present. In the abandoned bedroom, tones that are not present in the bunker bedroom can be identified at 8 Hz, 12.5 Hz and 80 Hz (Fig. 3). These tones are present at low wind speed and increase in sound pressure level with higher wind speeds, while maintaining the consistency of their shape.



A. Bunker vs. Abandoned bedrooms. Wind speed 0.9 m/s, westerly wind (290°), 03 Nov 2017, at 03:00H.



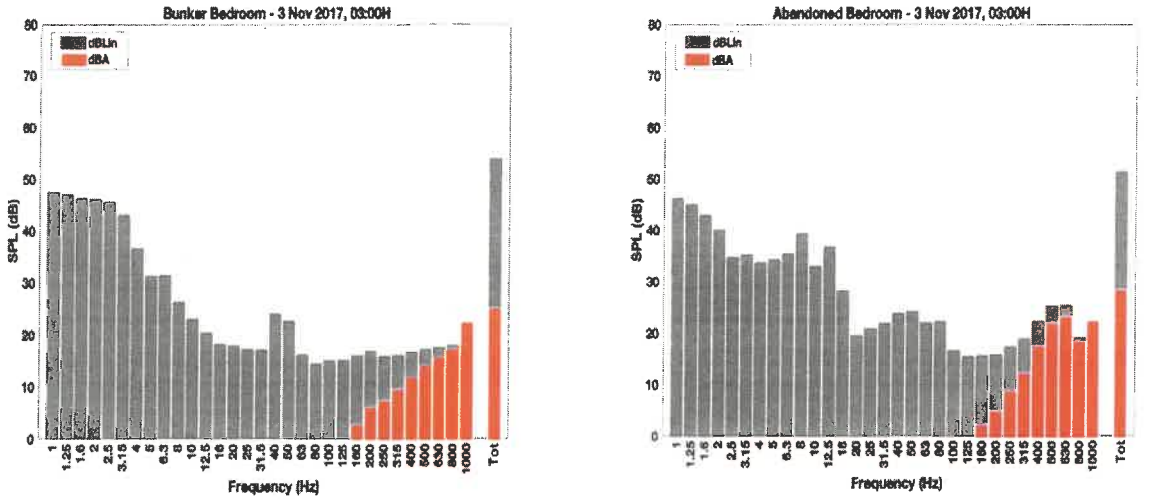
B. Bunker vs. Abandoned bedrooms. Wind speed 7.6 m/s, westerly wind (290°), 01 Nov 2017, at 14:00H

Figure 3: Periodograms covering the same 10-min intervals as in Figure 2 (analyzed between 1–1250 Hz), comparing the bunker and abandoned bedrooms at low and high wind speeds. The abandoned bedroom has consistently higher SPL levels than the bunker bedroom within the 4-40 Hz range, with very distinct shapes. At the lowest frequencies (≤2 Hz), SPL variations in both rooms have similar shapes and positions.

4. Discussion and Conclusions

Figure 4 shows ⅓-octave analyses obtained from a 10-min average, corresponding to the period shown in Figure 2A-B. In the bunker bedroom, the unweighted SPLs (Fig. 4A, grey bars) show a broad peak at about 50 Hz (or two narrower peaks on slightly either side). The highest SPLs are recorded below about 4 Hz. Unweighted SPLs in the abandoned bedroom (Fig. 4B, grey bars) show peaks at 8 and 12.5 Hz. There is relatively more energy in the abandoned bedroom above 4 Hz, but less below this. In both cases A-weighted SPLs (red bars) merely reflect that which humans would *hear* if present. As per Rule 012, this is the type of data required to establish permissible exposure levels.

Rule 012 was informally applied to the data obtained from the Hogeveen home. No recordings were made outside of the residence so the interior recordings used would a) be quieter than outside recordings and b) have a higher proportion of ILFN. The basic sound level is the lowest, 40 dBA, since it has less than 9 nearby dwellings within a 451-metre radius and is further than 500 m from a heavily travelled road. (Since outside night-time levels in the absence of IWT were impossible to measure, a 35-dBA level is assumed for the remainder of these calculations.)



A. Bunker Bedroom.

B. Abandoned bedroom.

Figure 4: These ⅓-octave frequency histograms cover the same 10-min interval as shown in Fig. 2A and B, wind speed 0.9 m/s and westerly wind (290°) on 03 Nov 2017, at 03:00H.

Two Class A adjustments are required. Assuming that a complaint is made in wintertime (the season during which these recordings were made), there is a +5 dBA adjustment. The ambient sound level with operational IWT is already 5 dBA below the basic sound level of 40 dBA, therefore, the adjustment is the maximum of +10 dBA. Since the sum of these two is +15 dBA, the maximum possible of +10 dBA is taken. For the Class B adjustment, two cases were considered: no increase occurs and one increase occurs for up to 60 days. This will give an adjustment of 0 dBA for the first case and +5 dBA for the second. The night time limit is therefore 40 dBA + 10 dBA + 0 dBA = 50 dBA for the base case, and 55 dBA is permissible for one period a year of up to 60 days. The daytime limit is the night-time value + 10 dBA = 60 dBA. The C-weighted and A-weighted overall sound levels for the 10-minute intervals captured on 01 and 03 November are shown in Table 2.

Table 2: dBC-dBA applied to the German data

	dBA Leq 10-min	**dBC Leq 10-min**	**Difference**
Bunker bedroom (01Nov)	35.7	56.2	20.5
Abandoned bedroom (01 Nov)	39.4	60.9	21.5
Bunker bedroom (03 Nov)	30.9	39.9	9.0
Abandoned bedroom [03 Nov)	33.7	42.7	9.0

Since these aspects of Rule 012 are stipulated in A-weighted sound levels, and the controversial features of IWT emissions are all in the ILFN regions, it is not surprising to find that these thresholds would very rarely be breached by IWT. The conclusion is that these aspects of Rule 012 are largely irrelevant. Moving, then, to the sections of Rule 012 dealing with ILFN, the question of whether significant components exist is determined by section 3.2 [7]. The difference in C-weighted and A-weighted sound levels must be 20 dB or more *and* there must be prominent, sharp peaks between 20 and 250 Hz. Figure 3 shows that there are prominent, sharp peaks in the bunker bedroom (blue lines) between 40 and 50 Hz. The abandoned bedroom does not show sharp peaks, therefore, they are not considered tonal, even though they are prominent. From the differences in the C-weighted and A-weighted sound levels, it can be seen that only the recording made on November 1, with high wind speeds, exceeds the 20-dB threshold. Ironically, this is because of the increased wind noise in the

ILFN regions. Section 4.5 (4) however, states that measurements should not be taken during high-wind-speed conditions for exactly this reason. Therefore, this aspect of the Rule also fails to catch the important soundscape features. Had it done, and the requirements of section 4.5 were met, the maximum penalty would be the addition of 5 dBA to the measured sound levels. If these then exceeded the limits (between 50 dBA and 60 dBA as above) then the operator would be required to implement noise attenuation measures and confirm that ILFN was no longer an issue.

When IWT are the source of ILFN, the rotating blades generate a series of pressure pulses at the 'blade pass frequency' (BPF), which is seen as a harmonic frequency series called *wind turbine signature* [14]. When synchronous IWT rotate at a constant rate, regardless of the wind speed, they will share a common harmonic series [15]. The IWT near the Hogeveen home are asynchronous, their BPF changes with wind speed. Given the sheer number of these IWT at the site, a single ('clean') IWT signature was not a reasonable expectation. Nevertheless, an analysis of the existence of harmonic series was conducted on the recordings of the abandoned bedroom, at low and high wind speeds.

Figure 5 shows the 1–100-Hz region of Fig. 3 with the harmonic series starting at 1.36 Hz added as dashed lines. The two main peaks at 8 and 12 Hz appear on this harmonic series as the 6th and 9th harmonics (H6 and H9). There is a large peak at 1.36 Hz for the higher wind speed. The 8 and 12 Hz peaks also appear on the harmonic series starting at 2.04 Hz; there is a small peak at 2.04 Hz. There is also a peak at 6.8 Hz on this series for the lower wind speed. A further harmonic series starting at 0.68 Hz includes these three peaks (1.36 Hz, 2.04 Hz and 6.8 Hz) as well as the broad peak at 3.45 Hz. There is no suggestion that peaks have moved between the two wind speeds although neither of the peaks (1.36 and 2.04 Hz) is seen at the lower wind speed. Note that the resonant frequencies of the bedroom are in the order of 60 Hz and upwards, with the peak just below 80 Hz likely being one such. The peaks discussed above are therefore less than $^{1}/_{10}$ of the cavity resonant frequencies and are not likely to be attributable to these phenomena.

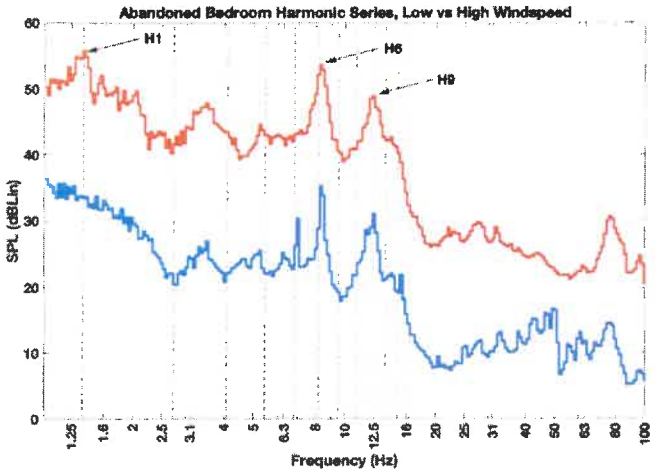


Figure 5: Comparison of data captured in the abandoned bedroom, at low (0.9 m/s-blue) and high (7.6 m/s-red) wind speeds, and same wind directions (290°). Harmonics of 1.36 Hz are shown as vertical, dashed lines.

A re-evaluation of legislation regarding population exposure to ILFN has been urgently required for decades [1]. The Canadian regulations here applied are similar to other regulations worldwide, and equally unsuitable *if* the goal is to protect human health against chronic ILFN exposures. Symptomatic complaints currently being ignored and/or misdiagnosed will predictably lead to a burden on future healthcare costs. Although the proliferation of IWT is bringing this agent of disease [16] to centre stage, the biases regarding how human health is impacted by airborne pressure waves (audible or not and whatever the source) continue to impede a proper scientific investigation [17], and consequently, proper protection of human populations and their offspring.

Acknowledgements: Author MAP would like to thank the Hogeveens for their kind contributions to acoustical data collection. Author CK would like to thank Wind Concerns Ontario for its contribution to the collection of citizen complaint information.

Financial Disclosure: Due to their efforts in the creation of the SAM Scribe system, authors HHCB, BIR and SRS have a financial interest in the SAM Scribe system.

REFERENCES

1 Alves-Pereira, M. Noise-induced extra aural pathology. A review and commentary. *Aviation, Space and Environmental Medicine*, **70** (3, Suppl.), A7-A21, (1999).

2 Ministry of Environment, Conservation and Parks. Spills Action Line. (2019). Retrieved January 11, 2019. https://www.ontario.ca/page/report-pollution-and-spills.

3 Wind Concerns Ontario. http://www.windconcernsontario.ca/

4 Environmental Review Tribunal. North Stormont v. Ontario (MOECC). Case No. 18-028. Appeal by Concerned Citizens of North Stormont of a Renewable Energy Approval, filed May 22, 2018. Retrieved January 27, 2019: http://elto.gov.on.ca/tribunals/ert/case-search/

5 Ministry of Environment and Climate Change. Ontario Environmental Review Tribunal. Nation Rise Wind Power Project. Renewable Energy Approval Appeal Case number 18-028. Concerned Citizens of North Stormont v. Director, Ontario, Witness Statement by Wilson EJ (June 20, 2018). PDF copy available on request.

6 Alberta Utilities Commission. Rule 012. http://www.auc.ab.ca/Shared%20Documents/rules/Rule012.pdf.

7 Alberta Utilities Commission. Description of Rule 012. http://www.auc.ab.ca/Pages/Rules/Rule012.aspx.

8 Kaeding, E.F. [The curse of repowering – A long descent]. *Die Tageszeitung*, 21 September 2014. (In German) https://www.taz.de/Archiv-Suche/!5032786&s=hogeveen/.

9 Wetzel, D. [Energy Danish Debate - Does the infrasound of wind turbines make you sick?]. *Die Welt*, 02 March 2015. (In German) https://www.welt.de/wirtschaft/energie/article137970641/Macht-der-Infraschall-von-Windkraftanlagen-krank.html.

10 Jung, F. [In Nordfriesland - The couple complains: 'Wind turbines make us sick']. *Schleswig Holstein Zeitung*, 02 January 2016. (In German) https://www.shz.de/deutschland-welt/politik/ehepaar-klagt-windraeder-%20machen-uns-krank-id12344191.html.

11 Atkinson & Rapley Consulting Ltd. Specification sheet for the SAM Scribe FS Mk 1. 2017. www.smart-technologies.co.nz.

12 Bakker, H.H.C., Rapley, B.I., Summers, S.R., Alves-Pereira, M., Dickinson, P.J. An affordable recording instrument for the acoustical characterisation of human environments. *Proceedings of International Conference in the Biological Effects of Noise*, Zurich, Switzerland, 18-22 June, (2017). http://www.icben.org/2017/ICBEN%202017%20Papers/SubjectArea05_Bakker_P40_3654.pdf.

13 Primo Co, Ltd. Specification sheet for the electret condenser microphone, custom-made, model EM246ASS'Y. Tokyo, Japan, 2017. http://www.primo.com.sg/japan-low-freq-micro.

14 Cooper, S. The results of an acoustic testing program Cape Bridgewater Wind Farm, prepared for Energy Pacific (Vic) Pty Ltd, Melbourne, Australia, (2014).

15 Alves-Pereira, M., Bakker H.H.C., Rapley, B., Summers, R. Infrasound and low-frequency noise – does it affect human health? *Engineers Ireland Journal*, 23 Jan (2018). http://www.engineersjournal.ie/2018/01/23/ilfn-infrasound-low-frequency-noise-turbine-health/

16 Alves-Pereira, M., Rapley, B., Bakker H.H.C., Summers, R. Acoustics and biological structures. IN: Abiddine, Z.E., Ogam, E. (eds), *Acoustics of Materials*, IntechOpen, London, UK (2019). DOI: 10.5772/intechopen.82761. https://www.intechopen.com/online-first/acoustics-and-biological-structures.

17 World Health Organization. Environmental Noise Guidelines for the European Region. Copenhagen, WHO Europe (2018). ISBN 978 92 890 5356 3. http://www.euro.who.int/en/publications/abstracts/environmental-noise-guidelines-for-the-european-region-2018.

ScienceDirect

Measurement

Volume 182, September 2021, 109678

Long-term quantification and characterisation of wind farm noise amplitude modulation

Phuc D. Nguyen [a], Kristy L. Hansen [a], Peter Catcheside [b], Colin H. Hansen [c], Branko Zajamsek [b]

Show more

https://doi.org/10.1016/j.measurement.2021.109678

Get rights and content

Highlights

- AM occurred 2 to 5 times more often during the night-time compared to the daytime.
- Indoor AM occurred 1.1 to 1.7 times less often than outdoor AM.
- A diurnal variation in AM prevalence was clearly observed.
- AM prevalence was associated with sunset and sunrise.
- AM occurred most often during downwind and crosswind conditions.

Abstract

The large-scale expansion of wind farms has prompted community debate regarding adverse impacts of wind farm noise (WFN). One of the most annoying and potentially sleep

I-32

disturbing components of WFN is amplitude modulation (AM). Here we quantified and characterised AM over one year using acoustical and meteorological data measured at three locations near three wind farms. We found that the diurnal variation of outdoor AM prevalence was substantial, whereby the nighttime prevalence was approximately 2 to 5 times higher than the daytime prevalence. On average, indoor AM occurred during the nighttime from 1.1 to 1.7 times less often than outdoor AM, but the indoor AM depth was higher than that measured outdoors. We observed an association between AM prevalence and sunset and sunrise. AM occurred more often during downwind and crosswind conditions. These findings provide important insights into long term WFN characteristics that will help to inform future WFN assessment guidelines.

Introduction

Wind energy is one of the fastest-growing renewable energy sectors in the world[1], reaching approximately 870 GW in 2021 (ref.[2]. Despite the benefits of wind energy, some concerns remain regarding social[3], [4], [5], ecological[6], [7] and environmental impacts[8], [9]. The noise generated by wind turbines is a recurring source of complaints regarding annoyance and potential sleep disturbance from residents living near wind farms[10], [11]. Wind farm noise (WFN) contains unusual spectral and time-varying features that may exacerbate annoyance[12] and increase loudness[13], including infrasound, a low-frequency dominated spectrum[14], [15], tonality[16] and amplitude modulation (AM), which is a periodic variation of the noise level primarily related to blade rotational effects[17]. Wind farm AM is commonly described as 'swish swoosh' or 'rumble' and is of particular research interest due to its propensity to contribute to annoyance[18], [19], [20] and possible sleep disturbance[21]. However, its characteristics such as depth (or degree), duration, consistency and occurrence time could vary between wind farms[22].

Previous long-term WFN measurements found wind farm AM to be associated with wind direction[23], [24], [25], sound speed gradient, solar elevation angle, turbulence intensity[24], and diurnal meteorological variations[23], [26]. The majority of these studies were carried out in cold climates where ground cover with snow during winter months and other climactic effects are clearly different from warmer climates without snow. Snow covered ground has a very high sound absorption coefficient, even at very low frequencies, and thus attenuates noise much more effectively than other ground surface types[17], [27], [28]. Previous long-term studies[23], [24] recorded only low time and frequency resolutions of acoustic data such as 1/3 octave bands or fast time-weighted SPLs which limited analyses to conventional AM detection methods[24], [29] unable to reliably detect AM. Long-term quantification of AM has been predominantly carried out at distances of 1 km or less from

wind farms, where WFN is dominated by mid to high frequencies (> 200 Hz). At larger wind farm setback distances, much more typical for Australia, AM is dominated by lower frequencies (< 200 Hz)[26]. However, to date, low-frequency AM has not been systematically studied over a long period of time. Furthermore, although indoor WFN noise character is much more relevant to human perception, annoyance and sleep disturbance than outdoor levels, long-term characterisation and quantification of indoor AM has not been attempted to date, especially at long-range distances to wind farm.

The purpose of this study was to quantify and characterise AM, and to examine relationships between AM, meteorological conditions and wind farm operational data over one year. To detect AM, we used a previously developed AM detection method based on machine learning[30]. This allowed for accurate and reliable detection of AM in three long-term acoustic data sets measured near South Australian wind farms at locations up to 3.5 km away from the nearest wind turbine.

Section snippets

Methods

This study was approved by the Flinders University Social and Behavioural Research Ethics Committee (SBREC project 7536). Residents living in the houses where measurements were conducted who provided voluntary informed written consent and received a small reimbursement for study involvement. ...

Amplitude modulation characteristics

AM occurred more often during the nighttime compared to the daytime (Fig.3a, two-sample t-test, all P-values < 0.001). At locations H1 and H2, which were within 1.3 km of the nearest wind turbine, AM occurred on average for more than 50% and 25% of the nighttime and daytime, respectively. Similar trends were also observed at location H3, but with a lower prevalence of around 25% AM during the nighttime and only 3% during the daytime, where the nighttime value is comparable to previous ...

Discussion

This paper presented long-term AM characteristics of WFN through analysis of acoustical and meteorological data measured at three South Australian wind farms. We showed

comprehensive information regarding the prevalence and diurnal distribution of AM at three locations with different wind farm layouts, wind turbine types, housing constructions and wind farm separation distances. The resulting estimates of AM depth, duration, frequency and associated sound pressure levels are important for both ...

Conclusion

In summary, this study characterised and quantified wind farm noise AM for a large data set measured over one year at three relatively long-range distances from three wind farms in South Australia. At nighttime, AM prevalence was lower indoors than outdoors, but there was an increase in AM depth in the indoor data. Our findings also showed a dependence of AM prevalence with respect to time (i.e.,diurnal and monthly variations). We further found that AM occurred more often during downwind and ...

CRediT authorship contribution statement

Phuc D. Nguyen: Conceptualization, Methodology, Data collections, Writing - original draft, Analysis and visualisation, Writing - review & editing. **Kristy L. Hansen:** Conceptualization, Methodology, Data collections, Supervision, Writing - review & editing. **Peter Catcheside:** Conceptualization, Methodology, Supervision, Writing - review & editing. **Colin H. Hansen:** Conceptualization, Methodology, Supervision, Writing - review & editing. **Branko Zajamsek:** Conceptualization, Methodology, Supervision, ...

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. ...

Acknowledgments

The authors gratefully acknowledge financial support from the Australian Research Council, projects DP120102185 and DE180100022 and the National Health and Medical Research Council, Project 1113571. The author PDN was supported by a Flinders University Research Scholarship (FURS) for this work. ...

References (49)

WolsinkM.
Wind power implementation: the nature of public attitudes: equity and fairness instead of 'backyard motives'
Renew. Sustain. Energy Rev. (2007)

KrohnS. *et al.*
On public attitudes towards wind power
Renew. Energy (1999)

LiuX. *et al.*
Tonality evaluation of wind turbine noise by filter-segmentation
Measurement (2012)

ConradyK. *et al.*
Amplitude modulation of wind turbine sound in cold climates
Appl. Acoust. (2020)

HansenK.L. *et al.*
Prevalence of wind farm amplitude modulation at long-range residential locations
J. Sound Vib. (2019)

HansenK. *et al.*
Outdoor to indoor reduction of wind farm noise for rural residences
Build. Environ. (2015)

MakarewiczR. *et al.*
The influence of a low level jet on the thumps generated by a wind turbine
Renew. Sustain. Energy Rev. (2019)

NgoT.T. *et al.*
Experimental study of topographic effects on gust wind speed
J. Wind Eng. Ind. Aerodyn. (2009)

Global Wind Report: Annual Market Update 2019
(2019)

Wind farms databases

(2021)

View more references

Cited by (17)

Effect of infrasound on the detectability of amplitude-modulated tonal noise

2023, Applied Acoustics

Citation Excerpt :

...The AM depth and tonal audibility ranges were between 2 and 12 dB and 5 and 17 dB, respectively, as quantified using the IOA [16] and IEC [17] methods, respectively. The amplitude modulation depth range is above average, which is approximately 2 dB in Australia [18], in order to simulate a conservative scenario expected to provoke an annoyance response. From each of the twenty 10-min long samples, only one 10-s sample was extracted....

Show abstract

Audibility of wind farm infrasound and amplitude modulated tonal noise at long-range locations

2022, Applied Acoustics

Citation Excerpt :

...For example, the difference in the sound pressure level (SPL) at some particular frequencies could be over 20 dB during wind farm operational versus non-operational conditions [19]. The difference could also be over 10 dB during nighttime versus daytime operational conditions [23]. However, measurement variability is rarely considered when assessing WFN....

Show abstract

Adverse environmental impacts of wind farm installations and alternative research pathways to their mitigation

2022, Cleaner Engineering and Technology

Show abstract

An experimental investigation on the impact of wind turbine noise on polysomnography-measured and sleep diary-determined sleep outcomes ↗

2022, Sleep

EEG power spectral responses to wind farm compared with road traffic noise during sleep: A laboratory study ↗
2022, Journal of Sleep Research

Amplitude modulated wind farm noise relationship with annoyance: A year-long field study ↗
2021, Journal of the Acoustical Society of America

> View all citing articles on Scopus ↗

View full text

Scientific Research Publishing

Open Journal of Social Sciences, 2017, 5, 166-185
http://www.scirp.org/journal/jss
ISSN Online: 2327-5960
ISSN Print: 2327-5952

Human Health, Rights and Wind Turbine Deployment in Canada

Carmen Krogh[1], Brett Horner[2]

[1]Independent Health Researcher, Killaloe, Ontario, Canada
[2]Independent Researcher, Killaloe, Ontario, Canada
Email: Carmen.krogh@gmail.com, brett.s.horner@gmail.com

How to cite this paper: Krogh, C. and Horner, B. (2017) Human Health, Rights and Wind Turbine Deployment in Canada. *Open Journal of Social Sciences*, 5, 166-185.
https://doi.org/10.4236/jss.2017.55012

Received: March 16, 2017
Accepted: May 14, 2017
Published: May 17, 2017

Abstract

Canada has ratified international conventions which recognize the individual's right to the enjoyment of the highest attainable standard of health. Despite the adoption of these covenants governments sometimes support policies and practises which trade off individual human health with other conflicting interests. This review evaluates the individual's right to health against government policies and practices which support wind energy deployment in Canada. Our analysis presents government documents, peer reviewed literature, and other references which support the conclusion that wind energy deployment in Canada can be expected to result in avoidable harm to human health. This harm conflicts with contemporary health and social justice principles. Governments have a responsibility to help Canadians maintain and improve their health by generating effective responses for the prevention of avoidable harm. Individuals have a right to make informed decisions about their health. Knowledge gaps and potential risks to health should be fully disclosed. Individuals should not be exposed to industrial wind turbines without their informed consent.

Keywords

Wind Turbines, Policies and Practices in Canada, Harm to Human Health, Human Rights, Social Justice

1. Introduction

Individuals in Canada enjoy the right to the highest attainable level of health and governments have a responsibility to help Canadians achieve this right. To this end Canada has developed health promotion frameworks aimed at achieving health for all. At the same time conflicting interests inherent in our society can result in inadequate health policies and practices and undermine the health and

I-33

quality of life of many Canadians. The deployment of industrial wind turbines (IWTs) in Canada presents a contemporary example of the individual's right to health in conflict with competing interests.

The global installed wind energy capacity has experienced rapid growth since 2001 [1]. Coinciding with the operation of IWTs, some individuals living in proximately report adverse health effects [2]. These negative effects can be avoided if IWTs are sited away from residents.

In Canada IWT deployment has been supported by government policy [3] [4], major government funding programs [3] [4] and legislation [5]. In addition some governments in Canada have developed IWT noise criteria which can be expected to result in adverse health effects [6] [7] [8] [9]. In some cases Canadian families reporting IWT adverse health effects have: abandoned their homes; or been billeted away from their homes; or hired legal counsel to successfully reach a financial agreement with the wind energy developer [2].

This review considers the definition of "health" adopted by Canada and the individual's fundamental right to its attainment. Policies and practices which support wind energy deployment in Canada are evaluated in the context of modern health frameworks and the responsibility of government to help maintain and improve the health of Canadians.

2. Materials and Methodology

A review of relevant treaties and covenants adopted by Canada since 1948 were evaluated to establish the following health principles:

- The definition of health
- The individual's right to health
- The individual's right to informed consent
- The role of governments to promote and protect health

Government frameworks were explored to understand, how Canadians can best achieve health, and that conflicting interests can undermine the health and quality of life of many Canadians.

Documents obtained from government publication, websites and Access to Information and Privacy (ATIP) requests were used to chronicle IWT policies and practises undertaken by government in Canada since 2005. These government policies and practices were evaluated against key health principles and health promotion frameworks adopted by Canada.

References cited in this review were retrieved from a variety of sources including:

- References published by governmental authorities in Canada,
- Documents obtained by federal Access to Information and Privacy (ATIP) requests,
- References published by, or for, members of the Canadian wind energy industry,
- References published by international health organizations,
- Peer reviewed literature,

- Grey literature, and
- Other references.

3. Canada and Health Principles

Canada has a historical role in the development of modern health doctrine intended to nurture a policy environment that supports health and where individuals of all ages and backgrounds can have an equitable chance of achieving health.

3.1. Canada, Health and Human Rights

Canada has described its governance structure as:

> ... a democratic constitutional monarchy, with a Sovereign as head of State and an elected Prime Minister as head of Government. Canada has a federal system of parliamentary government: Government responsibilities and functions are shared between federal, provincial and territorial governments [10].

Health Canada is the Federal department responsible for helping Canadians maintain and improve their health, while respecting individual choices and circumstances [11].

Canada has a universal health-care system where Canadian citizens and permanent residents enjoy the option of public health insurance [12] and The Canadian Charter of Rights and Freedoms guarantees "everyone has the right to life, liberty and security of the person and the right not to be deprived thereof except in accordance with the principles of fundamental justice" [13].

A Canadian Deputy Minister of Health, Dr. Brock Chisholm, became the first Director General of the World Health Organization (WHO) [14] [15] and was a co-draftee of the WHO definition of health [15].

> Canada, including both Health Canada and the Public Health Agency of Canada, continues to support the definition of health established by the WHO's ... constitution in 1948: Health is "a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity [16].

The stated objective of the WHO is "...the attainment by all peoples of the highest possible level of health" [17]. Canada has the distinction of being the Third Member State to ratify the WHO constitution [14] which in addition to providing Canada's definition of "health" declares "The enjoyment of the highest attainable standard of health is one of the fundamental rights of every human being without distinction of race, religion, political belief, economic or social condition" [17].

Canada is also a party to international human rights treaties [18] which recognize the individual's rights to the highest attainable standard of health [19] [20].

3.2. Health Promotion, Prevention and Protection

In 2005 Health Canada identified one of the "Current Issues of Greater Significance for Canada" to be "non-communicable disease prevention and control" [14]. Protection of "...Canadians from avoidable risks" remains a goal of Health Canada [11].

In 2012 The Public Health Agency of Canada confirmed Canada's approach to health is consistent [16] with the United Nations Political Declaration of the High-level Meeting of the General Assembly on the Prevention and Control of Non-communicable Diseases which recognizes the "...the primary role and responsibility of Governments in responding to the challenge of non-communicable diseases and the essential need for the efforts and engagement of all sectors of society to generate effective responses for the prevention and control of non-communicable diseases" [21].

In addition to supporting the WHO definition of health Canada has adopted "...two key documents... instrumental in focusing policy and program discussions on how health is created and how health can be achieved equitably by society as a whole" [22]. The two key documents are the Ottawa Charter on Health Promotion and Health Canada's Achieving Health for All: A Framework for Health Promotion [22].

The Ottawa Charter on Health Promotion "...defined the fundamental prerequisites for health as peace, shelter, education, food, income, a stable eco-system, sustainable resources, social justice and equity. It also recognized that access to these prerequisites cannot be ensured by the health sector alone. Rather, coordinated action is required among all concerned, including governments (health and other social and economic sectors) non-governmental organizations, industry and the media" [22].

Health Canada's Achieving Health for All: A Framework for Health Promotion called attention to three key health promotion challenges: reducing inequities in health; increasing the prevention of disease; and enhancing the capacity to cope with chronic disease and disability. The Framework recognises the need for a multi-sector cooperation "...to ensure that the collective policy environment is one that supports health" [22].

Canada recognizes the rights of individuals to be protected from arbitrary scientific experimentation and is a party to [18] the International Covenant on Civil and Political Rights which provides "...no one shall be subjected without his free consent to medical or scientific experimentation" [23].

4. Health Risks of Noise Includes Annoyance

Health Canada's "broad mandate to protect and maintain the health of Canadians-includes protecting people from risks in the environment they work, live and play..." and the "...public expects government to mitigate these risks ..." [24].

Exposure to IWT noise has been identified as a plausible cause of reported health effects [2].

The main health risks of noise identified by WHO are:

•pain and hearing fatigue;

•hearing impairment including tinnitus;

•annoyance;

•interferences with social behaviour (aggressiveness, protest and helplessness);

•interference with speech communication;

•sleep disturbance and all its consequences on a long and short term basis;

•cardiovascular effects;

•hormonal responses (stress hormones) and their possible consequences on human metabolism (nutrition) and immune system;

•performance at work and school [25].

Annoyance from noise is acknowledged to be a health effect [26] [27] [28] [29]. Health Canada explained that according to the WHO "... health should be regarded as "a state of complete physical, mental and social well being and not merely the absence of disease or infirmity" Under this broad definition, noise induced annoyance is an adverse health effect" [28].

The WHO pan-European LARES study explored impacts of annoyance in a sample that included children, adults and elderly participants. "The results of the LARES study - with regard to criteria for causal relations - confirmed, on an epidemiological level, an increased health risk from chronic noise annoyance" [30]. Consequently chronically strong annoyance must be classified as a serious human health risk [30].

The burden of disease of annoyance has been estimated. "Loss of health in populations is measured in disability-adjusted life years (DALYs), which is the sum of years of life lost due to premature death and years lived with disability" [31]. In western European countries, noise-induced annoyance is estimated to account for 587 000 DALYS. [32]

5. IWTs and the Well-Known Stress Effects of Noise

Some individuals residing in proximity to IWTs report experiencing adverse health effects.

Reported health effects include, but are not limited to, annoyance, sleep disturbance, stress-related health impacts and reduced quality of life. [2] [33]-[44]. Similarly occupational workers and technicians exposed to IWTs also have reported negative health effects [45]-[51].

IWT noise (unwanted sound), visual impacts (shadow flicker), stray voltage and socio-economic impacts are identified as plausible causes of adverse effects [2]. The National Research Council (2007) reports "...to the extent that wind-energy projects create negative impacts on human health and well-being, the impacts are experienced mainly by people living near wind turbines who are affected by noise and shadow flicker" [52].

Pierpont (2009) documented symptoms reported by individuals exposed to IWTs to include: sleep disturbance, headache, tinnitus, ear pressure, dizziness, vertigo, nausea, visual blurring, tachycardia, irritability, problems with concen-

tration and memory, and panic episodes associated with sensations of internal pulsation or quivering when awake or asleep [33]. Pierpont (2009) coined these symptoms "Wind Turbine Syndrome" [33].

In 2009 The American Wind Energy Association and Canadian Wind Energy Association (CanWEA) co-sponsored a literature review which "...undertook extensive review, analysis, and discussion of the large body of peer reviewed literature on sound and health effects in general, and on sound produced by wind turbines" [53]. Based on this review Colby *et al.* (2009) reported "Wind Turbine Syndrome" symptoms "...are not new and have been published previously in the context of "annoyance"..." and are the "...well-known stress effects of exposure to noise ..." [53]. Jeffery *et al.* (2014) confirmed the reported "...effects from exposure to IWTs are consistent with well-known stress effects from persistent unwanted sound" [2].

In 2011 CanWEA advised the public "the association has always acknowledged that a small percentage of people can be annoyed by wind turbines in their vicinity.... When annoyance has a significant impact on an individual's quality of life, it is important that they consult their doctor" [54]. McMurtry and Krogh (2014) [55] present a diagnostic criteria tool to assist practicing physicians who are presented with patients impacted by IWT annoyance [56].

6. Discussion

6.1. Health Principles and Conflicting Interests

The Ottawa Charter on Health Promotion "...highlighted the fact that health promotion action goes beyond the health care sector, emphasizing that health should be on the policy agenda in all sectors, and at all levels of government" [57].

Our review of government publications, documents and websites confirm the following health principles have been adopted and supported by Canada.

- Health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity.
- Individuals have a fundamental human right to the highest attainable standard of health.
- Governments have a shared a responsibility to help Canadians maintain and improve their health, while respecting individual choices and circumstances.
- A primary role and responsibility of government is to generate effective responses for the prevention and control of non-communicable diseases.
- No one shall be subjected without their free consent to medical or scientific experimentation.

While these principles provide underpinning for a socially just health doctrine, Health Canada's "Achieving Health for All" identifies major challenges which are not being adequately addressed by current health policies and practices including "...various forms of preventable diseases and injuries continue to undermine the health and quality of life of many Canadians" [58].

Tobacco is highlighted as a historical example of how government policy can trade off preventable harm for competing economic interests.

> Conflicting interests may exist between sectors. Such conflicts are intrinsic to our society. Take the example of tobacco. We are proponents of a smoke-free environment. On the other hand, there are Canadian farmers who cultivate this product for their livelihood. Changes in tobacco policies have implications for farmers and smokers alike. In this instance the creation of healthy public policy necessitates responding to a situation with serious health as well as economic implications [58].

This conflict between health and economic interests has continued to exist. In 2012, Health Canada reported "each year in Canada, second-hand smoke causes the death of at least 800 non-smokers, due to lung cancer and heart disease" [59]. Despite this avoidable harm, production of tobacco and tobacco products remain an active sector in Canada's economy. Statistics Canada reported Canadian manufacturers produced 21.5 billion cigarettes in 2014 [60].

Achieving Health for All acknowledges "...existing policies and practices are not sufficiently effective to ensure that Canadian men and women of all ages and backgrounds can have an equitable chance of achieving health..." [58]. We explore this understanding by reviewing government policies and practices for addressing potential health risks associated with two contemporary exposures; tanning equipment and IWTs.

6.2. Tanning Equipment, Health Promotion and Protection

The Radiation Emitting Devices Act (REDA) is federal legislation that regulates devices which emit energy in the form of electromagnetic waves or acoustical waves [61]. Health Canada has identified both tanning equipment [62] and IWTs [6] [7] [8] [63] as devices regulated under the authority of the REDA.

Exposure to tanning equipment in Canada typically occurs only with the consent of individuals. In 2014 Health Canada in collaboration with the Federal Provincial Territorial Radiation Protection Committee, released A Guideline published for Tanning Salon Owners, Operators and Users [64]. The Guideline identified health risk associated with tanning equipment and focused on prevention of avoidable harm recommending the use of tanning equipment, particularly by minors, be discouraged [64]. Health Canada has also strengthened "... the labelling requirements for tanning beds to better inform consumers about the health risks associated with the use of these devices" [65] and in 2014 new Ontario legislation came into effect which, among other things, bans the use of tanning beds by youth under 18 years of age [66].

These policies and practises demonstrate shared responsibility by multiple levels of government to help Canadians maintain and improve their health by: generating responses for the prevention and control of non-communicable diseases, protecting vulnerable populations; and providing disclosure of risks so that individuals can make informed decisions about their health.

6.3. Industry Led, Government Supported Wind Energy

After considering the evidence and testimony presented by 26 witnesses [67], a 2011 Ontario environmental review tribunal decision acknowledged IWTs can harm human health stating:

> This case has successfully shown that the debate should not be simplified to one about whether wind turbines can cause harm to humans. The evidence presented to the Tribunal demonstrates that they can, if facilities are placed too close to residents. The debate has now evolved to one of degree [68].

However, unlike tanning equipment, the use of IWTs has been encouraged by government in Canada. The Government of Canada has provided long time support for the wind energy. In 2005 Project Green indentified that in addition to environmental benefits , Canada's expanded Wind Power Production Incentive will "...build a new economic sector and position Canada to be a leader in a vibrant wind energy industry in North America and internationally" [4].

A 2006 Health Canada commissioned report identified wind energy as a "screened in" greenhouse gas mitigation technology supported by "Federal Climate Change Policy" and major funding programs [3].

As Canada emerged from the 2008 global economic crisis, the Government of Canada focused on jobs and the economy [69]. The Government of Canada's priorities included promoting economic growth, the continued expansion of Canada's international trade and creation of green jobs befitting its "... growing stature as a clean energy superpower" [69].

In 2012 Health Canada reported "Natural Resources Canada and Industry Canada in collaboration with industry stakeholders" [70] developed the Wind Technology Road Map (WindTRM). Natural Resources Canada describes WindTRM as "...an industry-led, government-supported initiative that has developed a long-term vision for the Canadian wind energy industry and identified the major technology gaps and priorities to achieve a major increase in deployment of wind energy in Canada" [71].

The WindTRM projected the creation of a minimum of 52,000 green jobs and "...also recognize[d] that Canada is competing for this investment with many other jurisdictions and that it is critical for Canada to establish a competitive investment policy framework. If no action is taken, Canadian industry will miss out on a huge part of the value chain that will be created in achieving the vision" [71].

6.4. Government IWT Noise Criteria

CanWEA describes itself as the "voice of Canada's wind energy industry" [72] and was a WindTRM participant [71]. In 2004 CanWEA advised "...noise regulations can have a significant impact on wind turbine spacing, and therefore the cost of wind generated electricity ..." [73]. The President of CanWEA has also explained IWTs are sited in populated areas because developers need access to transmission infrastructure [74].

Regarding noise-induced health effects:

> Health Canada considers the following noise-induced endpoints as health effects: noise-induced hearing loss, sleep disturbance, interference with speech comprehension, complaints, and change in percent highly annoyed (%HA) [75].

Commenting on IWTs Health Canada has repeatedly advised "annoyance with noise is a reliable and widely accepted indicator of health effects due to environmental noise" [76].

Health promotion frameworks and principles adopted by Canada suggest government IWT noise criteria would be informed by definitive scientific research and would not be expected to result in increased adverse health effects. This has not been the case in Ontario where provincial IWT noise guidelines have been developed [77]. Based on current knowledge, the sound from IWTs at the levels experienced at typical distances in Ontario is expected to result in a non-trivial percentage of persons being highly annoyed and contribute to stress related health impacts [9].

Health Canada does not have noise guidelines or enforceable noise thresholds or standards [75] however in 2007 and 2008 Health Canada published an IWT noise "justification" for 45 dBA and predicted an increase in %HA from 1.1 to 7.6 percent [6] [7] [8]. Some Canadian provinces have applied the Health Canada IWT 45 dBA noise criteria. For example the Province of Nova Scotia "...applies the federal guidelines for noise when granting approvals" [78].

Health Canada's predicted increase in %HA is not supported by other IWT noise research and appears to be underestimated. IWTs sound has been consistently shown to be perceived by humans to be more annoying than transportation or industrial noise at comparable sound pressure levels [42]. Annoyance from IWT noise starts at dBA sound pressure levels in the low 30's and rises at 35 dBA [42] [79] [80]. Dose response data for IWTs suggest, at a highest allowed immission level of 45 dB(A) it could be expected that "... less than 14% of the exposed population to be highly annoyed indoors by wind turbines and less than 29% to be highly annoyed outdoors" [81].

6.5. Health Canada IWT Noise Initiatives and Challenges

In 2005 Project Green and Health Canada and identified that

> [t]here is a need to develop a federal framework or mechanism to ensure health impacts of new technologies or other mitigation measures are assessed before they are widely deployed or commercialized [4] [24].

Health Canada identified challenges to meeting this need including "competition for resources for research and assessment leaves many health concerns and potential risks unaddressed" and as a solution proposed to "...expand government partnerships and involve private sector in environmental health research, in defining priorities and participating in surveillance." [24]

The 2010 Wind TRM declared "...members of the Steering Committee, government and our industry will be using this roadmap to direct the actions that are necessary for Canada to develop its vast wind resources" [71]. One of the "key action items" detailed in the Wind TRM calls for Government and Industry collaboration to develop and maintain government documents that address concerns raised about wind energy projects including that of noise, infrasound and other [71].

Health Canada became a member of the Interdepartmental Wind Technology Road Map Committee [82] created by Natural Resources Canada to assist in the implementation of Canada's WindTRM [83].

Also in 2010, Health Canada proposed the formation of the Federal, Provincial, Territorial (FPT) Working Group to contribute to the development of national guidelines on IWT noise [70] [78] [84]. Health Canada had proposed a 45dBA IWT noise criterion for these guidelines [78]. The FPT Working Group was suspended in January 2012 owing to the lack of consensus among the members [70]. One FPT member expressed concern that limits of less than 45dBA would result in a loss of prospective IWT sites and limit expansion of an existing project [78]. Another FPT Working Group member commenting on the guidelines stated "...I do not see these as health-based. I think we would be on more solid ground if the basis of these guidelines was something other than health" [78]. In February 2012, "Health Canada Policy and Research Approach for Wind Turbine Noise" declared Health Canada "...will explore research options and release guidelines only when knowledge gaps are filled" [82].

In 2012 Health Canada advised "... there is ongoing scientific uncertainty on whether there are other, possibly indirect, health effects associated with wind turbine noise, and if so, to what extent ... All existing studies have limitations, and there is a need for further research in this area." [70]

In June 2012, after years of providing advice on IWT noise, Health Canada disclosed "Health Canada's ability to provide advice on noise impacts from WTs has been challenged..." [85] and officially announced its 1.8 million dollar Health Canada Wind Turbine Noise and Health study (Health Canada Study). The announcement acknowledged the Health Canada Study has "limitations", would be not be definitive and was intended to inform policy [85]. Also in 2012, the Canadian Council of Academies (CCA) was engaged by Health Canada to conduct an assessment of the literature into possible health impacts of IWTs [82].

November 2014 summary results of the Health Canada Study reported high levels of annoyance associated with increasing levels of IWT noise and "...annoyance was found to be statistically related to several self-reported health effects including, but not limited to, blood pressure, migraines, tinnitus, dizziness, scores on the PSQI, and perceived stress" as well as related to "measured hair cortisol, systolic and diastolic blood pressure" [86]. Subsequently in 2015, the CCA released its review of the literature into possible health impacts of IWT noise [29] and announced "...annoyance can be caused by wind turbine noise—

a clear adverse health effect" [87]. While some IWT knowledge gaps had been previously identified [70] [88] [89] the CCA identified additional gaps and issues [29] and concluded "technological development is unlikely to resolve, in the short term, the current issues related to perceived adverse health effects of wind turbine noise" [90].

6.6. Exposure Without Consent

Achieving Health for All describes a "New Vision of Health" which "...recognizes freedom of choice and emphasizes the role of individuals and communities in defining what health means to them." [58]

Canada has ratified [18] the covenant that no one shall be subjected without their free consent to medical or scientific experimentation [23]. Some individuals in Canada may enter into contractual agreements with wind energy developers and accept potential risks of IWT exposure [91] [92]. However, unlike exposure to tanning equipment, exposure to ITWs can also be imposed on individuals without consent. Government has approved deployment of IWTs despite municipal governments having declared their jurisdictions to be unwilling hosts of wind energy projects [93] [94].

Individuals continue to be exposed without consent, and have formed part of the sample pool of potential subjects from which researchers have drawn data and/or biological samples for government sponsored IWT health studies [86] [95].

6.7. Government Responsibility and Future Liability

A 2006 Health Canada memorandum identified that "[g]reenhouse gas mitigation technologies and measures... may pose unintentional threats to human health..." and "...the Government of Canada has a responsibility to ensure that these technologies do not negatively impact the health of Canadians" [96]. Another Health Canada document reported "it is unclear if the recommendations from these funding programs ... are in the best interest of Canadians and also protect the Crown from future liabilities resulting from the widespread application of new technologies" [97].

In 2005, Health Canada had acknowledged Canada's Climate Change Plan had "...no systematic assessment of potential health risks of new processes, technologies or products..." and stated "we cannot afford to wait until the health of Canadians is affected before we act. We have the means, tools and knowledge to become proactive in protecting the health of our citizens, in particular those most at risk" [24]. Health Canada presented a "Health and Environment Framework" which was to focus on "health outcomes" and "population groups at risk" [24].

WHO identify children and elderly as populations more vulnerable to noise [98] and the Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans dictates children, at all stages of development, and the elderly shall not be inappropriately excluded from research solely on the basis of their

age [99]. However the Health Canada IWT Study excluded the vulnerable populations of children and elderly over 79 years [86].

6.8. Blaming the Victim

WHO reports healthy public policy "...puts health on the agenda of policy makers in all sectors and at all levels, directing them to be aware of the health consequences of their decisions and to accept their responsibilities for health" [100] and Achieving Health for All points out

> ...we cannot invite people to assume responsibility for their health and then turn around and fault them for illnesses and disabilities which are the outcome of wider social and economic circumstances. Such a "blaming the victim" attitude is based on the unrealistic notion that the individual has ultimate and complete control over life and death [58].

In 2009, the Minister of Labour advised

> Health Canada provides advice on the health effect of noise and low-frequency electric and magnetic fields from proposed wind turbine projects, particularly for environmental assessments done under the Canadian Environmental Assessment Act. To date, their examination of the scientific literature on wind turbine noise is that the only health effect conclusively demonstrated from exposure to wind turbine noise is an increase of self-reported general annoyance and complaints (*i.e.*, headaches, nausea, tinnitus, vertigo) [101].

Some commentators suggest negative attitudes toward IWTs may contribute to reported annoyance [102]. However, researchers have found that IWTs were initially welcomed into the communities for their perceived environmental [35] or economic [37] benefits. Krogh (2011) wrote.

> Individuals report they welcomed IWTs into their community and the negative consequences were unexpected...When the health symptoms became apparent, there was an expectation that authorities and/or the IWT developer would resolve the issues. Individuals report their distress intensified when attempts to obtain recognition of their situation failed. An unexpected lack of response from a cross section of society, including government officials, industry, medical practitioners led to an exacerbation of their situation [43].

Jeffery *et al.* (2014) reports the characteristics of IWT noise "...that are identified as plausible causes for reported health effects include amplitude modulation, audible low-frequency noise (LFN), infrasound, tonal noise, impulse noise and night-time noise" [2]. While suggesting infrasound impacts may be a non issue Health Canada's lead IWT noise investigator stated in 2013 "...subject matter experts seem to agree... that more attention should be directed towards low frequency noise (16 - 160 Hz), tones and amplitude modulation and how to better

model these impacts, including how these change across the seasons" [103].

Governments aware that the consequences of their IWT noise criteria include a predicted increase in %HA must accept responsibility for their health decisions and advice. On the other hand individuals exposed to IWTs cannot be faulted for ill health when the conclusively demonstrated health effects are a predicted outcome of government supported IWT noise criteria.

6.9. Summation

The case of wind energy deployment in Canada presents a contemporary example of individual achievement of health competing with conflicting interests intrinsic in our society. Canada has ratified the WHO constitution which recognizes the individual's right to health [17]. On the other hand, the government also supports a major increase in the deployment of wind energy in Canada [4] [71] IWT noise criteria have health implications for individuals exposed to IWTs as well economic implications for industry.

A primary role and responsibility of government is to generate effective responses for the prevention and control of non-communicable diseases. To be effective prevention responses should be informed by systematic assessments of potential health risks. Such assessments should commence with a comprehensive review of the literature and identification of all knowledge gaps. Ethical animal research targeted at resolving research gaps may then be considered. Any subsequent human research must be conducted only with the informed consent of the subject. Once definitive research has conclusively resolved the knowledge gaps, a IWT dose response relationship can be established to help inform standards aimed at preventing adverse health effects.

Health Canada's approach to IWT noise presents a different process. Health Canada acknowledged that "preferably the proposed criteria would be based on a dose response relationship that was specific to wind turbines" [6]. However Health Canada elected to base its 45dBA IWT noise criteria on traffic noise [6] [7] [8] and predicted an increase in the %HA. Recommendations which are predicted to result in adverse health effects conflict with governments' responsibility to help Canadians maintain and improve their health as well as the individual's fundamental human right to the highest attainable standard of health.

Health Canada's subsequent acknowledgment that its "... ability to provide advice on noise impacts from wind turbines has been challenged by limited scientific research and knowledge gaps..." [70] suggests the Government of Canada has not fulfilled its stated responsibility to ensure carbon mitigation technologies do not negatively impact the health of Canadians. The continued exposure of non consenting individuals to IWTs conflicts the covenant ratified by Canada that no one shall be subjected without their free consent to medical or scientific experimentation.

Health Canada, has identified the failure of government to ensure technologies do not negatively impact the health of Canadians may expose the Crown to future liabilities.

7. Conclusions

A review of key health principles adopted and supported by the Government of Canada was conducted. These key principles were contrasted against Government policies and practices which support wind energy deployment in Canada.

Government documents, peer reviewed literature, and other references presented support the conclusion that wind energy deployment in Canada can be expected to result in harm to human health. The resulting harm is avoidable and conflicts with the individual's fundamental human right to the highest attainable standard of health.

Governments have a responsibility to help Canadians maintain and improve their health by generating effective responses for the prevention of avoidable harm. Individuals have a right to make informed decisions about their health. IWT knowledge gaps and potential risks to health should be fully disclosed. Individuals should not be exposed to IWTs without their informed consent.

Acknowledgements

The authors thank the reviewers for their comments during the review process.

Financial Support and Sponsorship

None.

Conflicts of Interest

There are no conflicts of interest.

References

[1] Global Wind Energy Council (2017) Global Wind Statistics 2016. http://www.gwec.net/wp-content/uploads/vip/GWEC_PRstats2016_EN_WEB.pdf

[2] Jeffery, R.D., Krogh, M.E. and Horner, B. (2014) Industrial Wind Turbines and Adverse Health Effects. *Canadian Journal of Rural Medicine*, **19**, 21-26.

[3] Marbek Resource Consultants Ltd. (2006) Addressing the Health Risks of Climate Change Mitigation Technologies: A Discussion Paper Final Report Submitted to Health Canada. Marbek Resource Consultants Ltd., Ottawa.

[4] Government of Canada (2005) Project Green, Moving Forward on Climate Change a Plan for Honouring Our Kyoto Commitment.

[5] Government of Ontario (2009) An Act to Enact the Green Energy Act, 2009 and to Build a Green Economy, to Repeal the Energy Conservation Leadership Act, 2006 and the Energy Efficiency Act and to Amend Other Statutes. Government of Ontario, Toronto. https://www.ontario.ca/laws/statute/s09012#

[6] Keith, S.E., Michaud, D.S. and Bly, S.H.P. (2007) A Proposal for Evaluating the Potential Health Effects of Wind Turbine Noise for Projects under the Canadian Environmental Assessment Act. *Second International Meeting on Wind Turbine Noise*, Lyon, 20-21 September 2007.

[7] Keith, S.E., Michaud, D.S. and Bly, S.H.P. (2008) A Justification for Using a 45 DBA Sound Level Criterion for Wind Turbine Projects. *Canadian Acoustics*, **36**, 54.

[8] Keith, S.E., Michaud, D.S. and Bly, S.H.P. (2008) A Proposal for Evaluating the Po-

tential Health Effects of Wind Turbine Noise for Projects under the Canadian Environmental Assessment. *Journal of Low Frequency Noise, Vibration and Active Control*, **27**, 253-265. https://doi.org/10.1260/026309208786926796

[9] Howe Gastmeier Chapnik Limited (2010) Low Frequency Noise and Infrasound Associated with Wind Turbine Generator Systems: A Literature Review. Ministry of the Environment, Mississauga.

[10] Government of Canada (2011) Canada's System of Government.

[11] About Health Canada (2014). http://www.hc-sc.gc.ca/ahc-asc/index-eng.php

[12] Government of Canada (2017) Health Care in Canada. http://www.cic.gc.ca/english/newcomers/after-health.asp?_ga=1.76365141.1914082670.1442157853

[13] Constitution Act (1982) Canadian Charter of Rights and Freedoms. http://laws-lois.justice.gc.ca/eng/Const/page-15.html

[14] Heath Canada (2005) About Health Canada, World Health Organization. Archived June 24, 2013. http://www.hc-sc.gc.ca/ahc-asc/intactiv/orgs/organi-eng.php

[15] WHO (1998) WHO: From Small Beginnings. *World Health Forum*, WHO, Geneva. http://whqlibdoc.who.int/analytics/WHForum_1988_9(1)_29-34.pdf

[16] Public Health Agency of Canada (2012) David Butler-Jones, Correspondence Concerning the World Health Organization Definition of Health.

[17] WHO (1948) Constitution of the World Health Organization. http://www.who.int/governance/eb/who_constitution_en.pdf

[18] Department of Justice (2016) International Human Rights Treaties to Which Canada Is a Party. http://www.justice.gc.ca/eng/abt-apd/icg-gci/ihrl-didp/tcp.html

[19] Convention on the Rights of the Child (1991) http://www.ohchr.org/Documents/ProfessionalInterest/crc.pdf

[20] International Covenant on Economic, Social and Cultural Rights (1976). http://www.ohchr.org/Documents/ProfessionalInterest/cescr.pdf

[21] Political Declaration of the High-Level Meeting of the General Assembly on the Prevention and Control of Non-Communicable Diseases (2011). Adopted at the 3rd plenary meeting. 19 September 2011. http://www.who.int/nmh/events/un_ncd_summit2011/political_declaration_en.pdf

[22] Public Health Agency of Canada (2001) Population Health Promotion: An Integrated Model of Population Health and Health Promotion. http://www.phac-aspc.gc.ca/ph-sp/php-psp/php2-eng.php#Doing

[23] International Covenant on Civil and Political Rights (1976). http://www.ohchr.org/Documents/ProfessionalInterest/ccpr.pdf

[24] Glover, P. (2005) Innovation and Technology: Ensuring Health Benefits and Managing Risks for Canadians. Health Canada.

[25] World Health Organization Europe (2009) Noise. World Health Organization, Geneva.

[26] Berglund, B., Lindvall, T. and Schwela, D.H. (1999) Guidelines for Community Noise. World Health Organization, Geneva. http://www.euro.who.int/en/health-topics/environment-and-health/noise/publications

[27] Health Canada (2005) Community Noise Annoyance. http://www.hc-sc.gc.ca/hl-vs/alt_formats/pacrb-dgapcr/pdf/iyh-vsv/life-vie/community-urbain-eng.pdf

[28] Michaud, D.S., Keith, S.E. and McMurchy, D. (2005) Noise Annoyance in Canada. Noise Health. *The World Residences at Sea*, **7**, 39-47.

[29] Council of Canadian Academies (2015) Understanding the Evidence: Wind Turbine Noise. The Expert Panel on Wind Turbine Noise and Human Health. http://scienceadvice.ca/uploads/eng/assessments%20and%20publications%20and%20news%20releases/wind-turbine-noise/windturbinenoisefullreporten.pdf

[30] Niemann, H., Bonnefoy, X., Braubach, M., Hecht, K., Maschke, C., Rodrigues, C. and Robbel, N. (2006) Noise-Induced Annoyance and Morbidity Results from the Pan-European LARES Study. *Noise and Health*, **8**, 63-79. https://doi.org/10.4103/1463-1741.33537

[31] Smith, B.J., Tang, K.C. and Nutbeam, D. (2006) World Health Organization Health Promotion Glossary: New Terms, Health Promotion International Advance Access. http://www.who.int/healthpromotion/about/HP%20Glossay%20in%20HPI.pdf?ua=1

[32] World Health Organization (2012) Environmental Health Inequalities in Europe. World Health Organization, Geneva. http://www.euro.who.int/en/health-topics/environment-and-health/noise/publications/2012/environmental-health-inequalities-in-europe.-assessment-report

[33] Pierpont, N. (2009) Wind Turbine Syndrome: A Report on a Natural Experiment. K-Selected Books, Santa Fe.

[34] Krogh, C., Gillis, L., Kouwen, N. and Aramini, J. (2011) Wind Voice, a Self-Reporting Survey: Adverse Health Effects, Industrial Wind Turbines, and the Need for Vigilance Monitoring. *Bulletin of Science Technology & Society*, **31**, 334-345. https://doi.org/10.1177/0270467611412551

[35] Shepherd, D., McBride, D., Welch, D., Dirks, K.N. and Hill, E.M. (2011) Evaluating the Impact of Wind Turbine Noise on Health-Related Quality of Life. *Noise Health*, **13**, 333-339. https://doi.org/10.4103/1463-1741.85502

[36] Thorne, B. (2011) The Problems with Noise Numbers for Wind Farm Noise Assessment. *Bulletin of Science Technology & Society*, **31**, 262-290. https://doi.org/10.1177/0270467611412557

[37] Nissenbaum, M., Aramini, J. and Hanning, C. (2012) Effects of Industrial Wind Turbine Noise on Sleep and Health. *Noise Health*, **14**, 237-243. https://doi.org/10.4103/1463-1741.102961

[38] Pedersen, E. and Persson, K.W. (2004) Perception and Annoyance Due to Wind Turbine Noise—A Dose Response Relationship. *Journal of the Acoustical Society of America*, **116**, 3460-3470. https://doi.org/10.1121/1.1815091

[39] Pedersen, E. and Persson, W.K. (2007) Wind Turbine Noise, Annoyance and Self-Reported Health and Well Being in Different Living Environments. *Occupational and Environmental Medicine*, **64**, 480-486. https://doi.org/10.1136/oem.2006.031039

[40] Onakpoya, I.J., O'Sullivan, J., Thompson, M.J. and Heneghana, C.J. (2015) The Effect of Wind Turbine Noise on Sleep and Quality of Life: A Systematic Review and Meta-Analysis of Observational Studies. *Environment International*, **82**, 1-9. https://doi.org/10.1016/j.envint.2015.04.014

[41] Phipps, R., Amati, M., McCoard, S. and Fisher, R. (2007) Visual and Noise Effects Reported by Residents Living Close to Manawatu Wind Farms: Preliminary Survey Results.

[42] Pedersen, E., Bakker, R., Bouma, J. and Van den Berg, F. (2009) Response to Noise from Modern Wind Farms in the Netherlands. *Journal of the Acoustical Society of America*, **126**, 634-643. https://doi.org/10.1121/1.3160293

[43] Krogh, C.M.E. (2011) Industrial Wind Turbine Development and Loss of Social Justice? *Bulletin of Science Technology & Society*, **31**, 321-333. https://doi.org/10.1177/0270467611412550

[44] Copper, S. (2014) The Results of an Acoustic Testing Program. Cape Bridgewater Wind Farm, Melbourne.

[45] Swinbanks, M. (2015) Direct Experience of Low-Frequency Noise and Infrasound within a Wind Farm Community. *6th International Meeting on Wind Turbine Noise*, Glasgow, 20-23 April 2015.

[46] Abbasi, M., Monnazzam, M.R., Zakerian, S.A. and Yousefzadeh, A. (2015) Effect of Wind Turbine Noise on Workers' Sleep Disorder: A Case Study of Manjil Wind Farm in Northern Iran. *Fluctuation and Noise Letters*, **14**, 15 p.

[47] Abbasi, M., Monazzam, M.R., Ebrahim, M.H., Zakerian, S.A., Dehghan, S.F. and Akbarzadeh, A. (2016) Assessment of Effects of Wind Turbine on the General Health of Staff at Wind Farm of Manjil, Iran. *Journal of Low Frequency Noise, Vibration and Active Control*, **35**, 91-98. https://doi.org/10.1177/0263092316628714

[48] Abbasi, M., Monazzam, M.R., Akbarzadeh, A., Zakerian, S.A. and Ebrahimi, M.H. (2015) Impact of Wind Turbine Sound on General Health, Sleep Disturbance and Annoyance of Workers: A Pilot—Study in Manjil Wind Farm, Iran. *Journal of Environmental Health Science & Engineering*, **13**, 71. https://doi.org/10.1186/s40201-015-0225-8

[49] Inagaki, T. and Nishi, Y. (2014) Analysis of Aerodynamic Sound Noise Generated by a Large-Scaled Wind Turbine and Its Physiological Evaluation. *International Journal of Environmental Science and Technology*, **12**, 1933-1944. https://doi.org/10.1007/s13762-014-0581-4

[50] Ambrose, S.E., Rand, R.W. and Krogh, C.M.E. (2012) Wind Turbine Acoustic Investigation: Infrasound and Low-Frequency Noise—A Case Study. *Bulletin of Science Technology & Society* published, **32**. http://bst.sagepub.com/content/early/2012/07/30/0270467612455734

[51] Rand, R.E., Ambrose, S.E. and Krogh, C.M.E. (2011) Occupational Health and Industrial Wind Turbines: A Case Study. *Bulletin of Science Technology & Society*, **31**, 359. http://bst.sagepub.com/content/31/5/359

[52] National Research Council. (2007) Committee on Environmental Impacts of Wind Energy Projects, Environmental Impacts of Wind-Energy Projects. National Academies Press, Washington DC.

[53] Colby, W.D., Dobie, R., Leventhall, G., Lipscomb, D.M., McCunney, R.J., Seilo, M.T. and Søndergaard, B. (2009) Wind Turbine Sound and Health Effects: An Expert Panel Review. American Wind Energy Association and Canadian Wind Energy Association, Washington DC.

[54] The Canadian Wind Energy Association (2011) Responds to October 14, 2011 Statement by Wind Concerns Ontario. The Canadian Wind Energy Association, Ottawa.

[55] McMurtry, R.Y. and Krogh, C.M.E. (2014) Diagnostic Criteria for Adverse Health Effects in the Environs of Wind Turbines. *The Royal Society of Medicine*, **5**, 1-5. https://doi.org/10.1177/2054270414554048

[56] McMurtry, R.Y. and Krogh, C.M. (2016) Response to McCunney *et al.*: Wind Turbines and Health: An Examination of a Proposed Case Definition. *Noise Health*, **18**, 399-402. https://doi.org/10.4103/1463-1741.195805

[57] World Health Organization (1998) Health Promotion Glossary. http://www.who.int/healthpromotion/about/HPG/en/

[58] Health and Welfare Canada (1986) Achieving Health for All: A Framework for Health Promotion. http://www.hc-sc.gc.ca/hcs-sss/pubs/system-regime/1986-frame-plan-promotion/index-eng.php

[59] Health Canada (2012) Second-Hand Smoke. It's Your Health. http://publications.gc.ca/collections/collection_2012/sc-hc/H13-7-25-2011-eng.pdf

[60] Statistics Canada (2014) Production and Disposition of Tobacco Products.

[61] Radiation Emitting Devices Act (1985). Current to September 10, 2015. http://laws-lois.justice.gc.ca/PDF/R-1.pdf

[62] Health Canada (2011) Tanning and Its Effects on our Health. It's Your Health. http://www.hc-sc.gc.ca/hl-vs/alt_formats/pdf/iyh-vsv/life-vie/tanning-bronzage-eng.pdf

[63] Michaud, D. (2013) Environmental Review Tribunal. Health Canada Wind Turbine Noise and Health Study, Ontario.

[64] Health Canada and the Federal Provincial Territorial Radiation Protection Committee (2014) A Guideline Published for Tanning Salon Owners, Operators and Users.

[65] Health Canada (2014) Government of Canada Announces Stronger Labelling Requirements for Tanning Beds—Warning Labels Remind Users about Skin Cancer Risk. http://news.gc.ca/web/article-en.do?nid=819389&tp=1

[66] Ontario Ministry of Health and Long Term Care (2013) The Skin Cancer Prevention Act (Tanning Beds). http://www.health.gov.on.ca/en/public/programs/tanning/

[67] Jeffery, R.D., Krogh, C. and Horner, B. (2013) Adverse Health Effects of Industrial Wind Turbines (Commentary). *Canadian Family Physician*, **59**, 473-475.

[68] Erickson, V. (2011) Environmental Review Tribunal. www.ert.gov.on.ca/files/201108/00000300-AKT5757C7CO026-BHH51C7A7SO026.pdf

[69] Prime Minister of Canada (2015) Priorities.

[70] Health Canada (2012) Briefing Note to the Ministers Office: Update on the Development of Federal-Provincial-Territorial Guidelines on Wind Turbine Noise.

[71] Wind Technology Road Map Summary Report (2010). http://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/canmetenergy/pdf/fichier/81768/windtrm_summary_e.pdf

[72] About Canadian Wind Energy Association. http://canwea.ca/about-canwea/

[73] Canadian Wind Energy Association (2004) Letter to Neil Parish Re: Sound Level Limits for Wind Farms. Wind Energy Association, Ottawa.

[74] Hornung, R. (2010) Interview on Business News Network.

[75] Health Canada (2010) Useful Information for Environmental Assessments. Authority of the Minister of Health, Ottawa. http://publications.gc.ca/collections/collection_2015/sc-hc/H128-1-10-599-eng.pdf

[76] Health Canada. Obtained by Access to Information and Privacy Request.

[77] Ministry of the Environment (2008) Noise Guidelines for Wind Farms: Interpretation for Applying MOE NPC Publications to Wind Power Generation Facilities. Queen's Printer for Ontario, Toronto.

[78] Health Canada (2011) Federal-Provincial-Territorial (FPT) Working Group (FPT Working Group) for National Guidelines on Wind Turbine Noise.

[79] Møller, H. and Pedersen, C.S. (2011) Low-Frequency Noise from Large Wind Turbines. *The Journal of the Acoustical Society of America*, **129**, 3727-3744. https://doi.org/10.1121/1.3543957

[80] Michaud, D.S., Feder, K., Keith, S.E., Voicescu, S.A., Marro, L., *et al.* (2016) Exposure to Wind Turbine Noise: Perceptual Responses and Reported Health Effects. *Journal of the Acoustical Society of America*, **139**, 1443-1454. https://doi.org/10.1121/1.4942391

[81] Janssen, S.A., Vos, H., Eisses, A.R. and Pedersen, E. (2011) A Comparison between Exposure-Response Relationships for Wind Turbine Annoyance and Annoyance Due to Other Noise Sources. *Journal of the Acoustical Society of America*, **130**, 3746-3753. https://doi.org/10.1121/1.3653984

[82] Health Canada (2012) Health Canada Policy and Research. Approach for Wind Turbine Noise—A Presentation to the Science Advisory Board.

[83] Natural Resources Canada, Next Steps.

[84] Health Canada (2011) Obtained by Access to Information and Privacy Request.

[85] Michaud, D.S., Keith, S.E., Feder, K. and Bower, T. (2012) Health Impacts and Exposure to Wind Turbine Noise: Research Design and Noise Exposure Assessment. *Inter-Noise* 2012, New York, 19-22 August 2012, 3.

[86] Health Canada (2014) Wind Turbine Noise and Health Study: Summary of Results. http://www.hc-sc.gc.ca/ewh-semt/noise-bruit/turbine-eoliennes/summary-resume-eng.php

[87] Council of Canadian Academies (2015) Expert Panel Finds that Annoyance Can Be Caused by Wind Turbine Noise—A Clear Adverse Health Effect. http://www.scienceadvice.ca/uploads/eng/assessments%20and%20publications%20and%20news%20releases/wind-turbine-noise/WindTurbineNoiseNewsReleaseEn.pdf

[88] Chief Medical Officer of Health (2010) The Potential Health Impact of Wind Turbines.

[89] Rideout, K., Copes, R. and Bos, C. (2010) Wind Turbines and Health. National Collaborating Centre for Environmental Health, Vancouver.

[90] Council of Canadian Academies (2015) Understanding the Evidence: Wind Turbine Noise. http://scienceadvice.ca/en/assessments/completed/wind-turbine-noise.aspx

[91] Lease Agreement for Wind Power between a Lessor and Lessee. "Schedule "B", Lease Agreement for Wind Power, Canada.

[92] Lease Agreement for Wind Power between a Lessor and Lessee. Surface Lease for Wind Power Project, Canada.

[93] Ferguson E. (2016) No "Veto" for Areas Opposed to Energy Projects, Kingston Whig-Standard. http://www.thewhig.com/2016/03/31/no-veto-for-areas-opposed-to-energy-projects

[94] Wind Concerns Ontario. Not a Willing Host (2017). http://www.windconcernsontario.ca/not-a-willing-host/

[95] Jalali, L., Nezhad-Ahmadi, M.R., Gohari, M., Bigelow, P. and McColl, S. (2016) The Impact of Psychological Factors on Self-Reported Sleep Disturbance among People Living in the Vicinity of Wind Turbines. *Environmental Research*, **148**, 401-410. https://doi.org/10.1016/j.envres.2016.04.020

[96] Government of Canada Memorandum. Marbek Discussion Paper: Addressing the Health Risks of Climate Change Mitigation Technologies: Discussion Paper.

[97] Health Canada. Assessing and Managing the Human Health Risks of Greenhouse Gases Mitigation Measures and Technologies.

[98] World Health Organization (2012) Noise—Facts and Figures. http://archive.is/JqY9

[99] Canadian Institutes of Health Research, Natural Sciences and Engineering Research Council of Canada, and Social Sciences and Humanities Research Council of Canada (2014) Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans, December 2014. http://www.pre.ethics.gc.ca/pdf/eng/tcps2-2014/TCPS_2_FINAL_Web.pdf

[100] World Health Organization (1986) The Ottawa Charter for Health Promotion. *First International Conference on Health Promotion*, Ottawa, 21 November 1986. http://www.who.int/healthpromotion/conferences/previous/ottawa/en/

[101] The Honourable Rona Ambrose (2009) The Honourable Rona Ambrose, Minister of Labour.

[102] Knopper, L. and Ollson, C. (2011) Health Effects and Wind Turbines: A Review of the Literature. *Environmental Health*, **10**, 78. https://doi.org/10.1186/1476-069x-10-78

[103] Michaud, D. (2013) Health Canada Trip Report. 5*th International Wind Turbine Noise Conference*, Denver, 27-30 August 2013.