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REVIEW ARTICLE

'Wind turbine syndrome': fact or fiction?

A FARBOUD[1], R CRUNKHORN[2], A TRINIDADE[3]

Department of ENT Head and Neck Surgery, [1]Glan Clwyd Hospital, Rhyl, Wales, and [2]Department of Neurosurgery, Queen Elizabeth Hospital, Birmingham, England, UK, and [3]Department of ENT Head and Neck Surgery, James Paget Hospital, Great Yarmouth, England

Abstract

Objective: Symptoms, including tinnitus, ear pain and vertigo, have been reported following exposure to wind turbine noise. This review addresses the effects of infrasound and low frequency noise and questions the existence of 'wind turbine syndrome'.

Design: This review is based on a search for articles published within the last 10 years, conducted using the PubMed database and Google Scholar search engine, which included in their title or abstract the terms 'wind turbine', 'infrasound' or 'low frequency noise'.

Results: There is evidence that infrasound has a physiological effect on the ear. Until this effect is fully understood, it is impossible to conclude that wind turbine noise does not cause any of the symptoms described. However, many believe that these symptoms are related largely to the stress caused by unwanted noise exposure.

Conclusion: There is some evidence of symptoms in patients exposed to wind turbine noise. The effects of infrasound require further investigation.

Key words: Noise; Wind; Auditory Perception; Auditory Threshold

Introduction

There have recently been concerns, reported in the UK media, that living close to wind turbines causes health problems.[1] A constellation of symptoms, including tinnitus, vertigo, migraines and sleep deprivation (Table I), has been described by Pierpont, who first coined the term 'wind turbine syndrome'.[1–3] It is proposed that the symptoms described are caused by exposure to infrasound and low frequency noise produced by the wind turbines.

There are currently 4035 wind turbines in the UK, and this figure is set to triple.[4] Since there will be a corresponding increase in the population exposed to this low frequency noise, concerns about the health effects of wind turbines are likely to grow. This may result in an increase in patients presenting to their general practitioner and local ENT service.

This review addresses the otological effects of infrasound and low frequency noise, and reviews the available literature supporting the validity of wind turbine syndrome.

Methods

This review is based on a search for articles, using the PubMed database and Google Scholar search engine, which included in their title or abstract the terms 'wind turbine', 'infrasound' or 'low frequency noise', and which were published within the last 10 years. The defined search limits included English language, human trials, and either randomised control trials, meta-analyses, editorials, letters, clinical trials, case reports, comments or journal articles. Additional articles received following author correspondence were also included.

Definitions

Infrasound is defined as sound with a frequency of less than 20 Hz, and low frequency noise as sound with a frequency of less than 200 Hz.[5–7] Low frequency noise is generated by many everyday sources such as household appliances, transportation and industrial machinery.[8,9] There are natural sources of infrasound such as ocean waves and volcanoes, as well as internal sources such as the heartbeat and respiration. A child playing on a swing experiences levels of infrasound of approximately 110 dB.[10] Some large mammals may use infrasound for communication.[11]

Infrasound is commonly misinterpreted as sound that is inaudible. There is no definite delineation between what is audible and what is not. Studies have shown a hearing threshold as low as 4 Hz can be measured in an acoustic chamber, and 1.5 Hz for earphone listening.[12] Infrasound, if presented at a high enough level, may indeed be audible.[8,13] To

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TABLE I
CORE SYMPTOMS OF 'WIND TURBINE SYNDROME'[2,3]

Sleep disturbance
Headache
Visceral, vibratory &/or vestibular dysfunction
Dizziness, vertigo, unsteadiness
Tinnitus
Ear pressure or pain
External auditory canal sensation
Memory & concentration deficits
Irritability, anger
Fatigue, loss of motivation

become audible, the sound pressure level for a 20 Hz sound needs to be approximately 75 dB, compared with 4 dB for a 1000 Hz sound.[8,13]

Historically, infrasound and low frequency noise have attracted much adverse publicity mainly based on misunderstanding and media hype, with stories such as the worker who 'fell dead on the spot' and the ability of infrasound to 'knock down buildings'.[12,13] Wind turbine syndrome has reinvigorated these anxieties about possible adverse health effects of infrasound.[12,13]

Wind turbine noise

Wind turbines consist of a tower, a rotor (or hub), a set of rotating blades, and a nacelle which houses the generator and controls.[3] These tall and highly visible structures are often placed in open, rural areas – places where the level of background noise is typically low and the surroundings perceived as natural. Unsurprisingly, wind turbines are often viewed as both visual and auditory intruders.[5]

There are two sources of noise from wind turbines: mechanical noise from the gearbox and generator; and aerodynamic noise produced by the flow of air around the blades.[14] The latter tends to be the main source of problems.[3]

Under good conditions with low wind speeds, the sound of wind turbines can appear benign or 'difficult to discern above the rustling of trees', as described by the British Wind Energy Association.[8] However, in suboptimal conditions the aerodynamic noise varies as the blades turn with changes in the strength and direction of wind.[3] Several studies have indicated that this amplitude modulated sound, rather than being a constant, steady type of noise, is more easily perceivable, and hence more likely to cause annoyance or health symptoms.[3]

We know that wind turbines produce broad-band noise; however, unweighted sound measurements have shown that this noise is indeed dominated by infrasound with frequencies of less than 10 Hz, and that levels of more than 90 dB are generated for sounds around 1 Hz.[11,15,16]

Wind turbine syndrome

Some people have reported adverse symptoms which they have attributed to noise from wind turbines (Table I). Pierpont was the first to describe wind turbine syndrome.[2,3] Otological symptoms such as vertigo, tinnitus and ear pain have been reported, and have been proposed to be caused by prolonged exposure of the vestibulocochlear system to infrasound and low frequency noise.[2] Other reported symptoms include sleep disturbance, headaches and concentration problems. This collection of symptoms has been colloquially termed wind turbine syndrome, but this is not currently a clinically recognised diagnosis.[8]

Measuring noise

The World Health Organization has recognised that assessment measures for environmental noise are inadequate for evaluating noise with a large low frequency component, such as that produced by wind turbines.[12] This is for two reasons: firstly, the widespread use of A-weighting in sound measurement; and secondly, technical issues in the actual measurement process.

The term A-weighting refers to a filtering process which aims to simulate human hearing in the measurement of sound. A-weighting is recognised internationally and used in the vast majority of noise-related studies and legislation.[10,11] Humans are considered able to perceive sound between 20 and 20 000 Hz, but not uniformly. The A-filter de-emphasises all auditory energy with frequencies of less than 500 Hz, and completely ignores all auditory energy of less than 20 Hz, in an effort to estimate the noise thought to be actually processed by the ear.[10] Hence, much of the noise produced by a wind turbine is effectively ignored. The A-filter is not used in physiological studies of cochlear function.[8]

There are alternative weighting systems available which may be better suited to measuring sound with a predominantly low frequency component, namely: unweighted measurements, C-weighting (designed for 50–4000 Hz) and G-weighting (designed specifically for infrasound).[11,15] Studies support the view that these may better predict the effects of low frequency sound.[17]

The second problem in evaluating noise generated by wind turbines relates to a technical issue. Suitable instruments for measuring infrasound and low frequency noise are not widely available.[8] Most commonly used types of apparatus are insensitive to infrasound components such as those produced by wind turbines.[8]

Sound level meters also tend to measure noise by averaging the sound levels over a period of time. Hence, for fluctuating sound such as wind turbine noise, information about the quality of the noise and its corresponding perceived sound character may be lost.[11]

Studies tend to assess sound pressure levels under specific meteorological conditions (generally winds of 8 m/second at 10 m height).[18] Again, this may

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mean that specific characteristics present under different conditions are ignored.

The location is also important. As sound travels away from its source, the sound pressure level is affected both by absorption from ground cover and by a dilution effect as sound energy spreads out from its source.[11] Both these effects may play an important part in the subjective assessment of noise, and may be useful topics for future research.[12]

Regulations regarding noise

In contrast to ultrasound, there are no clear protection standards established for infrasound.[5] Infrasound and low frequency noise are not currently recognised as disease agents, and therefore there is no legislation regarding permissible exposure levels and dose–response relationships.[3]

Guidelines for noise management have been produced, such as the World Health Organization 1999 guidelines on community noise.[18] Unfortunately, these guidelines contain no specific reference to wind turbine noise.[11] The World Health Organization night noise guidelines (2007) do comment on wind turbine noise, and state that observable effects of night-time, outdoor wind turbine noise do not occur at levels of less than 30 dBA;[18] they also state that there is evidence to link prolonged exposure to adverse health effects if levels are greater than 40 dBA. This has led to a proposed sound level limit of 45 dBA for new wind farms in Canada.[18] A number of other countries have agreed upper limits of 80 dBA at 20 Hz frequencies and 20–40 dBA at 100 Hz.[12]

Wind turbines are a new source of community noise to which relatively few people have been exposed. As the number of wind turbines increases, with a corresponding increase in the number of people exposed, guidelines will be needed to indicate the maximum safe exposure to infrasound and low frequency noise.[18] Since infrasound also occurs regularly in other environments (e.g. industrial and military sites), appropriate recognition of adverse health effects is a relevant public health issue.[5]

What is known about the effects of infrasound and low frequency noise on the ear?

Sounds presented below the typical human audible range have previously been presumed to have no influence on the ear.[8] However, Alves-Pereira and Castelo Branco have utilised comparison with the electromagnetic spectrum: light is perceived by the eye at certain frequencies but not others (e.g. X-ray frequencies), however, despite not being perceived as light, we do of course know that excessive exposure to X-rays can cause severe biological damage.[10] Perhaps the situation is similar with sound: although low frequency noise may not be audibly perceptible, there may be physiological effects which are as yet unknown.[8] Responses to infrasound are not well documented, but there is some evidence that low frequency noise may indeed affect inner ear function.[5,16]

A recent functional magnetic resonance imaging study assessing the effects of low frequency noise on healthy volunteers found that auditory cortex activation was induced by low frequency exposure.[5] This was dependent on high sound pressure levels (i.e. thresholds of 90–110 dB in normal hearing adults). The cortical activation patterns suggested that low frequency noise was processed through acoustic pathways in a similar way to noise frequencies within the main hearing range.[5]

A review by Salt and Hullar has described in detail the possible effects of infrasound as mediated by the inner ear.[8] These authors have described how hearing perception by the inner hair cells of the cochlea, the main hearing pathway in mammals, is indeed insensitive to infrasound. However, other structures of the inner ear (e.g. the outer hair cells of the cochlea) are more sensitive to infrasound and low frequency noise, and can be stimulated at levels below those normally perceived as audible.[8]

The outer hair cells of the cochlea send information to the brain via type two afferent fibres, nerves which were previously thought to be unresponsive to sound but which seem to respond to the static position of the organ of Corti. The outer hair cells are stimulated via direct contact with the tectorial membrane as it moves in response to sound. This displacement of the tectorial membrane remains sensitive at lower frequencies. Therefore, the outer hair cells are more sensitive at lower frequencies, including those below the audible range.[8]

The outer hair cells of the cochlea have been shown to respond to sound at frequencies and levels such as those produced by wind turbines, suggesting that this type of low frequency noise may well influence inner ear physiology. However, whether this actually alters function or causes symptoms is currently unknown.[8]

Aural pain is another proposed symptom of wind turbine syndrome. This usually arises due to mechanical displacement of the middle ear beyond its comfortable limits: this requires high sound pressure levels, such as 165 dB at 2 Hz or 145 dB at 20 Hz.[15,16] It has been postulated that noise from a wind turbine may produce sensations of fullness, pressure or tinnitus; however, there is currently no firm evidence to support this.[15,16]

What is known is that the variation in human response is wide.[11] There is no doubt that some humans exposed to infrasound and low frequency noise experience abnormal ear symptoms that are stressful, and the effects of this can be far-reaching.[11]

What is known about the effects of infrasound and low frequency noise on other systems?

Infrasound and low frequency noise have been controversially described as potential health hazards, causing

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various somatic and psychosomatic disorders such as chronic fatigue, sleep disorders, hypertension and vibroacoustic disease.[5] There has been ongoing debate about whether acoustic phenomena can cause extra-auditory effects in humans.[10] The role of alternative receptors has been discussed in the literature, with questions arising about the possibility of a hierarchy of sound receptors some of which may be more important at lower frequencies.[12] The remote possibility of a currently unknown, highly sensitive receptor remains, but there is no clear evidence of this.[12]

What is known is that wind turbine noise is annoying.[18] Any unwanted noise leads to annoyance, a symptom which can be moderated by multiple personal and social characteristics.[12] Wind turbine noise appears to be more annoying than other noise at similar levels, such as transportation or industrial noise, possibly due to specific sound qualities and lack of night-time abatement.[3,18] The low frequency nature of the sound also means it is less likely to be masked by other environmental noise.[3] Pederson *et al.* have demonstrated a dose–response relationship between A-weighted sound pressure levels from wind turbines and annoyance.[14,18] Other interesting factors noted to be significant are visibility of the turbine and whether or not the responder benefits economically from the wind turbine.[18,19]

It is also known that high levels of low frequency noise induce body vibrations, most prominently chest resonance vibration in the range of 50–80 Hz.[13] The lower a sound's frequency the longer its wavelength, which means resonance may occur in an enclosed or partially open space such as a room in a house, as well as within the body.[11] This vibratory sensation is one of the main contributors of the human response to low frequency noise, and may well be perceived as an ill effect.[9]

Sleep disturbance is another symptom commonly reported in case studies of low frequency noise. A large body of evidence now exists to suggest that wind turbines do disturb sleep and impair health at distances and sound pressure levels that are permitted in the UK.[20]

Alves-Pereira and Castelo Branco have described a multisystem disorder occurring secondary to excessive exposure to infrasound and low frequency noise, which they have named vibroacoustic disease.[10] This is characterised by the abnormal proliferation of collagen and elastin in people exposed to low frequency noise, in the absence of an inflammatory process.[3] These authors' work was initially based on observations of aircraft technicians regularly exposed to infrasound and low frequency noise. The manifestations described are wide, ranging from mild behavioural disturbance to epilepsy, arrhythmias and malignancies.[3,12] Vibroacoustic disease, like wind turbine syndrome, remains unproven and has not found general acceptance within the scientific community.[12]

Variation in response

Certain individuals may have more sensitive perception of low frequency noise than others.[5,13] Such noise may be perceived as sound or vibration, or not heard at all.[3]

The hearing threshold itself is a median value for an otologically normal young adult. Therefore, some individuals will be more sensitive and some less sensitive, such that a noise that is inaudible to one person may well be troublesome to others.[12] In addition, the dynamic range of the auditory system at low frequencies is such that a very slight increase in sound pressure level at a low frequency can change the perceived loudness from barely audible to very loud.[5,13,17] Clinical conditions involving changes to endolymph volume regulation, such as Ménière's disease, may well further enhance an individual's sensitivity to low frequency noise.[8]

It is possible that long term exposure to unwanted sound can lead to enhanced perception of that sound.[7,12] Studies have shown the brain has plasticity, exemplified by the findings of a study of London taxi drivers, who were shown to have an enlarged posterior hippocampus in response to their time spent navigating around London.[12] A few people with highly sensitive hearing have been discovered among low frequency noise plaintiffs investigated; however, usually there is little difference between the hearing thresholds of those who complain about low frequency noise and those who do not, suggesting higher centre involvement.[12]

Wind turbine noise affects people differently. Public concerns about low frequency noise tend to be based around work on subjective effects.[12] Subjective and personal issues are bound to be involved; for example, people living in rural areas may well have moved there for the peace and quiet, and hence a negative reaction to wind turbines is unsurprising.[19] Indeed, some have suggested that personal and social factors can be so variable that it may not be feasible to develop a national noise policy.[12]

What is not known?

There is an abundance of information available on the internet describing the possibility of wind turbine syndrome. However, the majority of this information is based on purely anecdotal evidence.[2] Whilst it is biologically and physically plausible that low frequency noise generated by wind turbines could affect people, there is insufficient evidence on which to base conclusions.[1] The fact that the ear may respond to low frequency noise at the frequency and levels generated by wind turbines does not necessarily mean that such noise will be perceived or will disturb function.[8]

Another important factor is length of exposure. There are currently no reported studies which come close to replicating the long term exposure to low frequency noise experienced by individuals who live

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near wind turbines.[15] This may be a topic for future study.

A better understanding is needed in order to deal with low frequency noise, to establish why some people are more sensitive than others, and to allow modelling of acceptable exposure levels.[14,15] The complexity of the ear's response to low frequency noise suggests that there are many aspects which should be better understood before the influence of wind turbine noise on the ear can be dismissed as insignificant.[15,16]

Conclusion

There is ample evidence of symptoms arising in individuals exposed to wind turbine noise. Some researchers maintain that the effects of wind turbine syndrome are clearly just examples of the well known stress effects of exposure to noise, as displayed by a small proportion of the population.[21] However, there is an increasing body of evidence suggesting that infrasound and low frequency noise have physiological effects on the ear.[8] Until these effects are fully understood, it is impossible to state conclusively that exposure to wind turbine noise does not cause any of the symptoms described. The effects of infrasound and low frequency noise require further investigation.

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Address for correspondence:
Mr Amir Farboud,
Department of ENT Head and Neck Surgery,
Glan Clwyd Hospital,
Bodelwyddan,
Rhyl LL18 5UJ, Wales, UK

Fax: +44 (0)1745 583 910
E-mail: amirfarboud@doctors.net.uk

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