

Wind Turbine Noise and Health in the New Zealand Context.

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1. EXECUTIVE SUMMARY

- Sound is what we hear, and noise is unwanted sound.
- Sound, be it unwanted or wanted, influences not only the way we think and behave, but also our physiological systems including cardiovascular and gastrointestinal activities, and hormone secretion.
- It is often claimed that continual exposure to a noise results in habituation, that is, one gets used to the noise. Such a proposition is not supported by either research or anecdotal evidence.
- There is now convincing evidence in the literature to conclude that community noise induces annoyance, disrupts sleep, impairs children's school performance, and negatively impacts cardiovascular health. It also impedes rest, relaxation, and recreation activities.
- The latest research indicates that annoyance with wind turbine noise is associated with psychological distress, stress, difficulties to fall asleep, and sleep interruption.
- Annoyance to noise, which can compromise health in susceptible individuals, is poorly predicted by the physical properties of the noise.
- Community noise, including noise emanating from wind turbines, can induce sleep disturbances by waking a sleeper, altering sleep patterns, reducing dream sleep, increasing body movement, and changing cardiovascular responses.
- Inadequate sleep has been associated not just with fatigue, sleepiness and cognitive impairment but also with an increased risk of obesity, impaired glucose tolerance (risk of diabetes), high blood pressure, heart disease, cancer, depression and impaired immunity as shown by susceptibility to the common cold virus.
- The evidence as it stands indicates that wind turbine noise has the potential to degrade psychological, physical, environmental and social well-being. All these factors combine to determine an individual's quality of life.
- Wind turbine installations need to be sited with care and consideration with respect to the communities hosting them.

2. ABBREVIATIONS

dB	Decibels
Hz	Hertz
<i>n</i>	Number of subjects
NIHL	Noise Induced Hearing Loss
SPL	Sound Pressure Level
WHO	World Health Organisation
WTI	Wind Turbine Installation

3. WHAT ARE WIND TURBINES? WHAT ARE WIND FARMS?

Wind turbines are man-made structures designed to harvest wind energy and transform it into electricity. The concept of converting wind into usable electricity is itself not new, and the conversion of the wind's kinetic energy into mechanical energy, and from mechanical energy into electricity, dates back over 100 years. According to the World Wind Energy Association (2009) wind power meets about 2% of the world's electricity demand. Structurally, wind turbines can be classified into two varieties based on the axis of blade rotation: horizontal axis (the most common) or vertical axis turbines. Both types, however, share common structural features (refer Figure 1). First, wind turbines possess a rotor, consisting of one-or-other type of blade designed to rotate when exposed to wind. The rotor can be thought of as a type of sail, catching wind in order to induce movement. On industrial-sized turbines the tip of the rotor may exceed 90 meters per second, equal to 324 kilometres per hour. The second major component is the generator or 'dynamo'. The generator component includes a gearbox to control the speed of the rotors, and the transducer that ultimately converts the mechanical energy into electricity. Lastly, the tower supports the rotor and usually the generator. The size of a wind turbine can be specified either as a dimension (e.g., meters high) or as an output (e.g., watts). Currently, turbines range from approximately two to two hundred meters high, and from about 50 watts to 6 megawatts.

Wind turbines can be erected in isolation or in sets. Utility-scale wind energy generation, involving the saturation of an optimum number of wind turbines in a fixed area, gives rise to the concept of the 'wind farm'. However, the term 'wind farm' is a misnomer (Kamperman and James, 2008). They are not farms in any sense of the word; rather they are large industrial complexes. For this reason the term 'Wind Turbine Installation' (WTI), which captures the industrial function of the turbines, will be used through out this monologue.

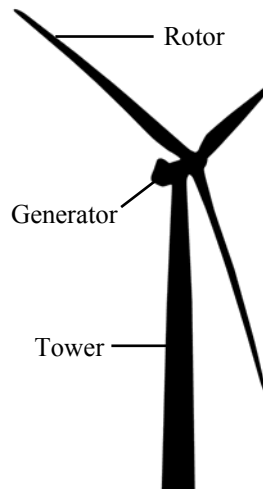


Figure 1: Schematic illustration of a wind turbine and its gross components.

4. WHAT IS NOISE?

Sound is what we hear, and noise is a type of sound. Thus before going on to discuss noise and its effects on health, a lay definition of sound will be attempted.

Sound

Sound waves are defined as airborne vibrations that stimulate sensory receptors in the ear. The description of both the structure and behaviour of sound waves is well advanced, and a dedicated area of physics ('acoustics') provides us with descriptions such as that presented in Figure 2. Figure 2 presents the basic building block of the sound wave, the sine wave. For simplicity's sake it will be assumed that a sine wave can be specified completely by its amplitude and by its frequency. The amplitude of a sine wave is indicated by the height of the peaks and troughs of the wave. The amplitude, or *level*, of an acoustic sine wave is usually represented by the decibel, or in abbreviated form "dB", which should always be accompanied by a suffix specifying how it was calculated. One of the many examples would be dB SPL, where the suffix (i.e., SPL) tells us that the measurement was made relative to a predefined international standard: Sound Pressure Level. As a sound wave increases in amplitude, so too does the perception of loudness. For example, an increase of 10 dB SPL is, as rule of thumb, perceived to be approximately twice as loud. As a sound wave travels away from its source, for example the explosion from a discharged pistol, the amplitude of the sound wave decreases according to well defined laws.

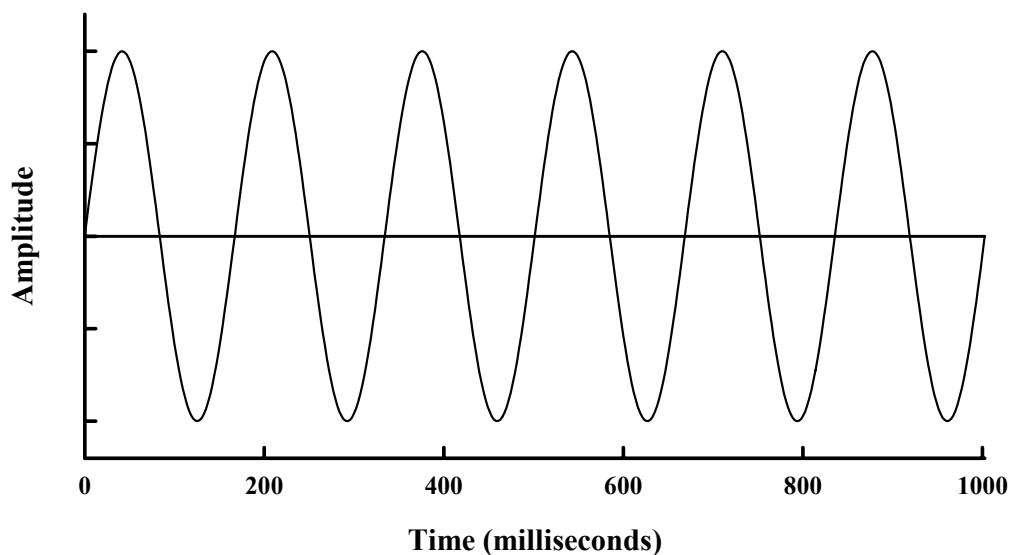


Figure 2: A simple sine wave showing changes in amplitude across time. This sine wave has a duration of one second (i.e., 1000 milliseconds) and thus a frequency of six hertz.

Frequency represents the rate at which the sine wave repeats itself, and is measured in units of Hertz, which is cycles-per-second. In Figure 1 the frequency of the sine wave is six hertz. Frequency corresponds to perceptions of pitch. Low frequency sine waves (around 25 hertz) produce a rumble or bass sound (e.g., the keys on the far left of a piano), while high frequency sounds (4000 Hertz and above) produce sounds with higher pitches (e.g., the keys on the far right of the piano). The audible range of frequencies for a normal functioning ear is approximately 20 hertz to 20,000 hertz, though hearing loss and the aging process act to restrict this range. In the everyday world we do not encounter sine waves presented in isolation. Instead, what arrives at the ear is akin to an acoustic pizza, where the different toppings represent different frequencies and the quantity of each topping across the pizza represents the amplitude of each frequency. Thus, what the ear really receives as an individual navigates their way about the world looks more like Figure 3 than Figure 2, though it should be noted that Figure 3 is in fact constructed from a multitude of sine waves which at any instant in time have a set amplitude and frequency.

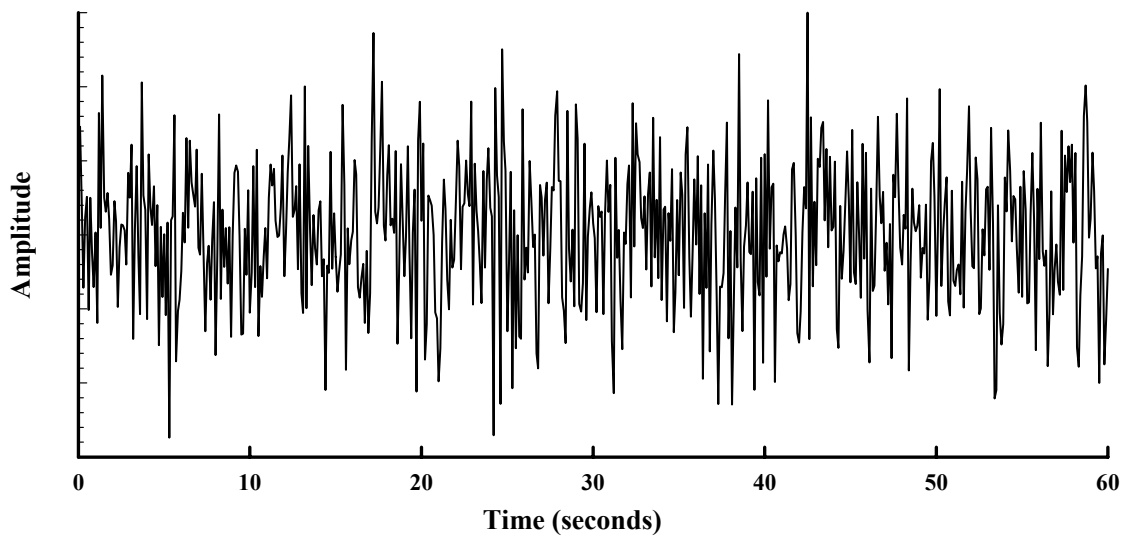


Figure 3: A one-minute sample of acoustic energy taken from a busy cafeteria. At any one instant in time this sample can be decomposed into many individual sine waves such as the six-hertz example presented in Figure 2.

The processing of sound waves by the ear and the subsequent interpretation of that sound by the brain constitutes the process commonly known as hearing. Hearing allows humans to detect threats in the environment and to communicate with others. Sound, whether it is unwanted or wanted, has the capacity to evoke reflexive and emotional responses, and can be a stimulant or a stressor. Sound arouses people by activating areas in the brain that regulate our mental states such as alert, relaxed, sleepy etc. The hearing senses are always on high alert, even during sleep. This alertness confers smoke alarms with their potency, for although then other senses are numbed or disabled during sleep (including the ability to smell smoke) the auditory modalities are not. Indeed, in humans hearing is the most acute sense, and in controlled conditions a person with normal hearing can detect vibrations of less than half a nanometre: approximately the diameter of a hydrogen atom. The range of sounds a properly functioning human ear can detect is likewise impressive, ranging from the smallest perceptible amplitude to amplitudes that are 10,000,000,000,000 times greater.

Noise

Noise is unwanted sound, that is, a sound that is judged undesirable, irritating, discordant with one's expectations, and that interferes with wanted sounds. In everyday life we are constantly exposed to sounds emanating from our environment. Not everything we hear, unfortunately, is classified as wanted sound. Commonly identified sources of noise include barking dogs, rowdy neighbourhood get-togethers, construction sites or road works, loud music, car engines, or low flying aircraft. Annoying or intrusive sound emanating from road, wind turbines, rail and air traffic, industries, construction and

public works, or the neighbourhood is known as community noise. Community noise is classified by the World Health Organisation (WHO) as a common pollutant. What is and what is not noise is highly subjective, and one person's noise is another's music. Thus noise pollution can be viewed as comparative to a certain extent, with substantial individual differences existing with respect to personal perception, sleep disturbance, annoyance, and irritation. Noise then is a psychological phenomenon that is determined by many seemingly diverse factors, and cannot be defined by recourse to acoustical factors alone.

5. DO WIND TURBINES GENERATE SOUND? DO THEY MAKE NOISE?

Whether sited in isolation or as a WTI, wind turbines produce sound audible to those living in their close vicinity. If this sound annoys or disturbs the sleep of an individual, then the turbine/s can be classified as a generator of community noise. One individual living in the vicinity of a turbine described the noise thus (Harry, 2007):

“The noise is like a whooshing noise. It’s intrusive. It keeps me awake”

What is meant by “vicinity” is, unfortunately, a matter of opinion and, furthermore, sometimes conflict between acousticians and those exposed to WTI sound. The swishing or thumping impulsive noise associated with wind turbines seems to be particularly annoying as the frequency and loudness varies with changes in wind speed and local atmospheric conditions. While there is no doubt of the occurrence of these noises and their audibility over long distances, up to four kilometres in some reports, the actual cause of the swishing or thumping has not yet been fully elucidated (Bowdler, 2008). Stigwood (2008), however, has demonstrated that this swishing or thumping noise pattern is common with larger turbines. This issue will be picked up in a subsequent section dedicated to annoyance. Another contentious issue, and one that acousticians quarrel over with some spite, relates to the characteristics of the sounds produced by wind turbines and WTIs, in particular, the frequency content of the sound waves.

Developers and supporters of WTI often make the claim that the sound emitted by wind turbines is congruent with natural habitats and aesthetically pleasing. Sometimes developers and their contracted acousticians will compare WTI sounds to rustling leaves or flowing streams. It follows then, that WTI sounds cannot be considered noise in the formal sense as people generally do not find such sounds annoying or disturb sleep. In fact, the little research that has been undertaken on the sound properties of wind turbines concludes just the opposite. Research has indicated (see Figure 4) that people are significantly more annoyed by equivalent sound levels produced by turbines than by aircraft, road traffic, or railway sources (Pedersen et al., 2004/2007; van Den Berg et al., 2008), possibly due to the unique acoustical characteristics of turbine noise. The most recent research in this area (van den Berg, 2008) has confirmed the relationship reported in Figure 4, which is reproduced in Figure 5.

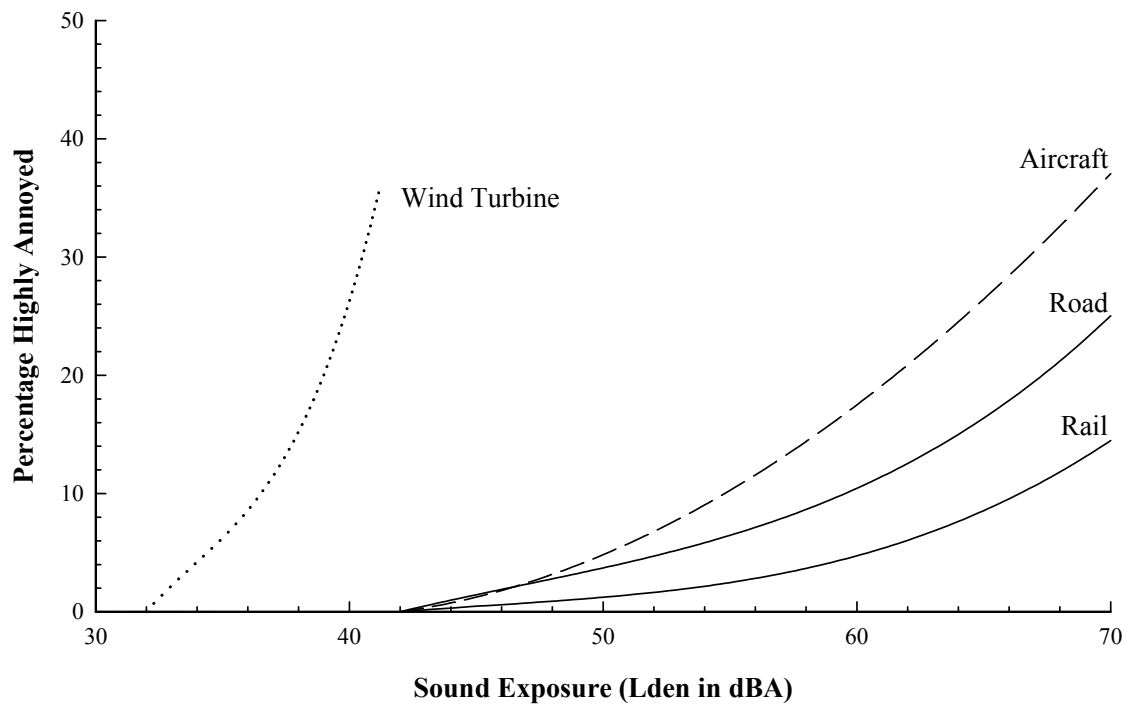


Figure 4: Comparison of annoyance and “loudness” (i.e., sound exposure) of four types of community noise. Figure based on Pedersen and Persson Waye (2004).

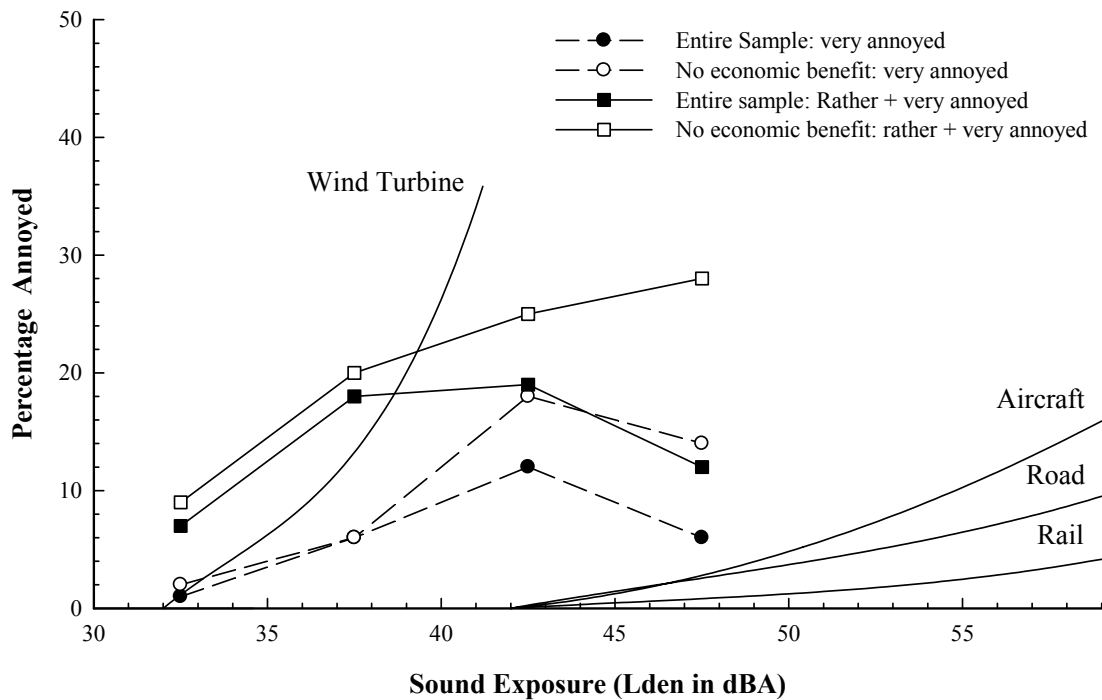


Figure 5: Annoyance plotted as a function of noise level for four theoretical models (rail, road, air: Miedema and Oudshoorn, 2001; wind turbines: Pedersen et al., 2004) and four sets of data obtained from van der Berg et al., (2008). For the data, closed symbols are for the entire sample, while open symbols are for those who identified that they had no economic interest. Circles represent the percentage of “very annoyed” responses whilst squares represent the sum of “very annoyed” and “rather annoyed” responses.

A further consideration is the manner in which people process naturally occurring sounds (e.g., rustling leaves) and otherwise unnatural sounds (e.g., the hum of an air conditioner). It has long been known that different regions of the human brain are activated when looking at living (e.g., a dog) or nonliving (e.g., a hammer) things, or when looking at natural (e.g., a river) versus manmade objects (e.g., a car). It has also been shown that people respond more negatively to man-made noise than natural noise (Nosulenko, 1990), and so it possible that the brain’s hearing processes mimic those associated with the visual processes.

6. WHAT IS HEALTH?

Before considering any possible impact of wind turbine noise on health a precise definition of health must be adopted. Such a task is not laborious however, as the WHO did precisely that during its formation in 1948. The WHO (1948) defines health as:

“A state of complete physical, mental and social well-being and not merely the absence of disease or infirmity”

Thus health refers not only to physiology functioning, but also well-being, quality of life, and amenity. Quality of life, as defined by WHO (1997), is a multifaceted concept:

“An individual’s perception of their position in life in the context of the culture and value systems in which they live and in relation to their goals, expectations, standards and concerns. It is a broad ranging concept affected in a complex way by the person’s physical health, psychological state, personal beliefs, social relationships and their relationship to salient features of their environment”

In its 2008 World Health Report, the WHO recommitted itself to the concept of primary health care and acknowledged that good health exists not in the hospital, but in the community. Primary health embraces the concept of health in all policies (e.g. labour, environment, education), and so includes not only the treatment of disease, but also its prevention. At the community level good health can be facilitated not only by the pursuit of healthy lifestyles (e.g., exercise and diet), but also the provision of restful and restorative living environments. A prominent factor determining the restfulness of a living space is the level of privacy and intrusion by community pollutants, including smell, air quality, and noise. In New Zealand, the guardianship of public health and quality of life is central to the Resource Management Act. For example, Section 5(2) of the Act states:

“managing the use, development and protection of natural and physical resources in a way, or a rate, which enables people and communities to provide for their social, economic and cultural wellbeing and for their health and safety.”

In the next section it will be argued that, when the WHO definition of health is adopted, noise impacts adversely on the quality of life and health of those who are exposed to it. These impacts can occur for traffic noise, rail noise, aircraft noise, as-well-as for wind turbine noise. Furthermore, the unwanted health effects of community noise can be temporary or long-term, and noise exposure can produce impairment of physical health, psychological wellbeing, or social functioning (Berglund and Nilsson, 1997).

7. CAN COMMUNITY NOISE COMPROMISE HEALTH?

For some, the notion that living beside a busy road, an airport, or a WTI can degrade health and quality of life is ridiculous. For others, the invasion of their personal spaces by intrusive noise constitutes a form of torture that severely degrades their general health and wellbeing. That different individuals respond differently to noise should not be a surprise. After all, we all know people who can remain asleep even though surrounded by loud sounds, or who can work undisturbed as loud music blasts from the radio. Contrastingly, some awaken at the sound of a pin dropping or a mosquito buzzing, and become positively irate as their work colleagues sing along to music that is not to their taste. This variation across individuals can give us clues as to why, for some people but not others, community noise can be a health issue, and how community noise affects the predisposed at the physiological level of description. Research is increasingly showing

that it is the response of the listener to noise, and not noise level *per se*, that best predicts health outcomes. For example, the meaning assigned to the noise by the listener (e.g., intrusive, unnecessary) is more likely to determine any aversive responses, than noise level.

Sufficient evidence now exists to link community noise to health problems, with one literature review concluding the following (EnHealth, 2004):

“It can be seen that these international groups of experts considered that there was sufficient evidence for the effects of noise on health regarding annoyance, school performance, ischaemic heart disease, hypertension, and various aspects of sleep disturbance.”

While the WHO noise report states (Berglund et al. 1999):

“People may feel a variety of negative emotions when exposed to community noise, and may report anger, disappointment, dissatisfaction, withdrawal, helplessness, depression, anxiety, distraction, agitation or exhaustion...”

The WHO has identified noise as a key issue in most European countries (Niemann & Maschke, 2004), and acknowledges both the increase in levels of community noise and the discontentment from the exposed communities (Berglund et al. 1999). Many health institutions now view the growth of community noise as unsustainable, and note that noise exposure is not simply limited to a direct and cumulative impairment to health, but to future generations who will be affected through the degradation of residential, social, and learning environments (Berglund and Lindvall, 1990). These warnings are in line with the stance taken by the WHO, whom state (Berglund et al. 1999):

“The growth in noise pollution is unsustainable because it involves direct, as well as cumulative, adverse health effects. It also adversely affects future generations, and has socio-cultural, aesthetic and economic effects.”

While it can be convincingly argued that community noise can be a source of stress and depression (Davis, 2007; EnHealth, 2004; Niemann & Maschke, 2004; Harry, 2007) and anxiety (Hardoy, 2004), there is currently no compelling evidence to suggest that community noise induces serious mental disorders such as psychosis or neurosis (Berglund et al. 1999). A WHO report on the relationship between health and noise demonstrated that those strongly annoyed by traffic noise were more at risk for depression, hypertension, and migraines (Niemann & Maschke, 2004). In relation to wind turbines, the French Academy of medicine (FAoM, 2006) states:

“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. Studies conducted in the neighbourhoods of airports have clearly demonstrated that chronic invasive sound involves neurobiological reactions associated with an increased frequency of hypertension and cardiovascular illness. Unfortunately,

no such study has been done near wind turbines. But, the sounds emitted by the blades being low frequency, which therefore travel easily and vary according to the wind, they constitute a permanent risk for the people exposed to them.”

Unfortunately there is little data available that would allow us to generalize the findings of the European studies to the New Zealand context. Some relevant data, collected as part of a longitudinal study entitled the Pacific Islands Family study, identified 15% of the sample as having serious concerns about neighbourhood noise, with 44.3% having some concerns (Carter et al. 2009). The proportion of those seriously concerned with neighbourhood noise exceeded all other neighbourhood issues including rubbish in the street (7.3%), walking around after dark (9.4%), smells and fumes (6%), and traffic and road safety (9.3%).

Acute vs. chronic exposure, and habituation

Most people, at one time or another, have become annoyed or have had their sleep disrupted by an unwanted sound intruding into their home, workplace, or place of rest and recreation. In isolation, such acute (i.e., of short duration) disturbances do not constitute a health risk, aside from a possible temporary change in mood and perhaps the need for an extra cup of coffee or two. However, research is increasingly showing that chronic (i.e., long term) exposure to unwanted sound can compromise health, and, furthermore, that these adverse reactions to noise do not disappear with repeated exposures.

It is proposed that adverse reactions to noise can reduce over time, a process known as habituation, which is a mental, and not a sensory phenomenon. Habituation is a form of learning describing a progressive decline in the tendency to respond to an event (e.g., sound exposure) because of repeated exposure to those events. While some individuals will habituate or develop coping strategies over time, not all will. For example, when community noise is introduced into an established community then, over time, annoyance and sleep disturbance levels are substantially greater than would be predicted (Griffiths & Raw, 1989; Pedersen & Wayne, 2008). This disparity between theory and reality can be explained by the meaning that people attach to the noise, and that habituation is not a given. Those who take the noise to be meaningless or non-threatening will rapidly habituate to it, while those who view the noise as a threat to their lifestyles and well-being will not. For example, noise sensitive individuals (a trait discussed later in the section headed “annoyance”) are less likely to habituate to noise. Additionally, research has demonstrated that those with a mental illness find it more difficult to habituate to community noise (Harry, 2007). As Brigitta Berglund, the author of the 1999 WHO report on community noise states (Berglund et al. 1999):

“Habituation is, however, a highly individual matter...”

New Zealand Data collected from individuals living around the Auckland International Airport (Mathews, 2009) exhibited no relationship between reactions to noise and how long they had resided in their current abode. That is to say, across the sample, annoyance

to aircraft sound had not decreased with length of stay. Research reported in the USA by the National Institute for Occupational Safety and Health asserts that continuous exposure to noise does not usually end with habituation, and instead the effects become more severe. A recent small study (Pirrera et al. 2009) looking at the effects of traffic noise on sleep efficiency supports the notion that habituation does not occur, while Griefahn and colleagues (2008) have shown that the increases in heart rate with traffic noise-induced arousals likewise show no habituation. Finally, not only may habituation to unwanted sounds be unlikely, but it is not uncommon that sounds in which one is neutral to, or may initially find pleasant, becomes annoying after repeated exposure (e.g., advertising jingles, popular music on the radio).

Who decides if noise is a health issue?

Numerous reports from credible institutions (e.g., the WHO) and universities around the world have demonstrated that noise negatively impacts our physiological and psychological processes. These findings have been replicated in laboratories, which confer greater experimental control at the cost of ecological validity, and in the real world, which provide ecological validity at the cost of experiment control. Researchers who are experts in human physiology, human psychology, or both have undertaken such research. On occasion these researchers will invite acousticians to assist in the generation (for laboratory studies) or measurement (for real world studies) of sound waves in order to increase the value of their research. Thus while the contribution of acousticians can be critical in the research process, there has been a noticeable trend in the field of public policy that, when the effects of noise on the community are being debated, acousticians are adopting the role of health experts. British medical doctor Dr Harry reports the alarming prevalence of acousticians giving evidence with regards to the health effects of sound emitted from wind turbines (Harry, 2007):

“...the acoustic experts have made statements categorically saying that the low frequency noise from turbines does not have an effect on health. I feel that these comments are made outside their area of expertise and should be ignored until proper medical, epidemiological studies are carried out by independent researchers.”

Another American practitioner, Dr Nina Pierpont (2009, p. 207), portrays the role of the acoustician in the monitoring of WTI sound levels as hired report writers rubber stamping a pre-existing script:

- 1) The WTI is emitting sound of this character and magnitude.
- 2) Acousticians have decided that there will be no adverse health effects for sounds of this character or magnitude.
- 3) Anyone claiming compromised health due to the sound emanating from the WTI is a hypochondriac, mentally ill, or a liar.
- 4) Case closed.

This somewhat mercenary portrayal will, however, resonate with some communities in the Manawatu region who would claim to have been on the receiving end of such treatment. For example, the Manawatu Times (2005) reported the following statement from Meridian Power, the owner of a newly established wind turbine installation, that “it’s a small number of people making a big noise about nothing” when locals complained of a rumbling sound that “bombarded us with noise and vibration”. Meridian Power justified these comments on the basis of the advice they had received from their employed ‘health consultants’, whom were in fact acousticians providing information far beyond their expertise.

With reference to Pierpont’s first point, a comment is justified on the value of the acoustic measurements undertaken using modern processes. Acousticians make a common mistake in believing that just because a sound frequency does not reveal itself in the physical measurement of acoustic energy (i.e., on a spectrograph) then that frequency cannot be perceived. This is contra to how the auditory system operates, and the phenomena of the missing fundamental and dichotic pitch make immediate nonsense of such claims. Along with the resident nonlinearities of the auditory system there are other psychoacoustical phenomena such as stochastic resonance that account for the perception of tonal components that fail to register on an acoustician’s sound meter. Stochastic resonance is a phenomenon by which subthreshold signals (e.g., a tone) are boosted above threshold by a coupling of energy between the signal and the noise background.

Every trained psychoacoustician knows that sensation does not perfectly mimic physics. Instead, we process stimuli in a “top-down” manner, and our judgments on what is happening in the immediate environment are reliant on how the brain interprets the sensory information, with this interpretation involving many nonsensory factors. Therefore, more weight should be placed on psychoacoustical, as opposed to acoustical, measurements in determining the effects of wind turbine noise. After all, a machine cannot be relied upon to tell a human what they are, and what they are not, hearing. Acousticians should be invited to the party, they can inform debate with physical measurements, but unless sufficiently qualified they should not be estimating the potential health effects associated with noise. Ultimately, medical practitioners, physiologists, and psychologists are required for these judgments.

8. THE HEALTH EFFECTS OF NOISE

Physical vs. non-physical health effects of noise

It is well known that some noises degrade our hearing; it’s why one wears earmuffs when mowing the lawn and why smoke detectors or house alarms are not pleasant to be around when activated in our immediate vicinity. However, direct impairment to the hearing sense (i.e., the ear) is not the only way that noise can compromise health. In the last decade evidence has emerged for other sorts of noise effects including irritability, stress, and poor sleep, all of which can compromise health and quality of life. A significant challenge in studying these other, “non-physical”, health effects brought on by unwanted

sound is that individuals report different responses to noise ranging from highly tolerant to highly reactive. As a result, while one individual may be completely indifferent to a particular sound, another may elicit an emotional reaction severe enough to induce poor health. The question becomes, if noise can induce deficits in health, then how? Figure 6 displays what is called a stimulus-response, or ‘black-box’, representation of noise and health. In this model the actual physiological and psychological processes associated with the individual are not accounted for, and instead the direct link between noise and health is the relationship of interest. Such a stimulus-orientated approach is a poor predictor of noise-induced health effects, and more comprehensive models that open up the ‘black boxes’ are required. Note that the box labelled “Health Effects” would include both physical (e.g., lowered immunity, cardiovascular disease) and psychological illness (e.g., anxiety and depression).

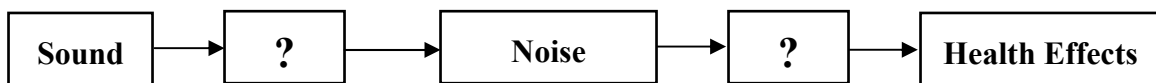


Figure 6: Stimulus-response model of noise and health. The boxes containing the query symbol (?) represent a ‘black box’, containing physiological and psychological processes that are not used to explain how a sound may become noise, and how a noise may impact health.

Figure 7 is a gross summary of noise-induced health effects which adds additional complexity to that displayed in Figure 6. In this model the potential adverse effects are categorised as either *physical* or *non-physical effects of noise*, and though on occasion the literature refers to the *auditory* and *non-auditory effects of noise*, they are not the same thing. The physical effects of noise (broken lines, Figure 7) include Noise Induced Hearing Loss (NIHL) and Vibroacoustic Disease (VAD). The non-physical effects (Solid lines, Figure 7) include sleep disturbance and annoyance, both which are moderated by predisposing factors associated with the individual and with the physical properties of the noise itself. Note too that there is an interaction between sleep and annoyance, meaning that disturbed sleep may amplify any annoyance response, while a strong annoyance response may lead to poor sleep. The two pathways will now be examined, with the greater emphasis conferred on the non-physical pathway.

The physical effects of noise

The physical effects of noise are characterised by structural deficits induced by exposure to noise of sufficient duration and amplitude. Thus impairment is a consequence of brute force, where sound waves produce irreversible damage to the ear due to excessive volume (NIHL) or when chronic exposure to acoustic energy degrades specific components of biological cells (e.g., the cell wall). For sound waves emanating from wind turbines or WTI there is no credible evidence to suggest that NIHL will occur, and NIHL will not be discussed further in this monograph. Before moving on however the

phenomena of vibroacoustic disease will be briefly discussed, which at the time of writing is a hotly debated topic at WTI consent hearings.

It has been proposed that noise can also impact physical health even though it is beyond the range of normal human hearing. Studies show that humans exposed to low frequency noise exhibit elevated cortisol levels and generalized cell damage: a condition known as vibroacoustic disease (Castelo-Branco & Alves-Pereira, 1999/2004) abbreviated to VAD. Vibroacoustic disease is a recognised disease caused by chronic exposure to infrasound and low frequency noise, and there now exists over 37 peer reviewed articles in the medical literature. Infrasonds are low frequency (less than 20 Hertz) sound waves that are not necessarily perceived as a sound by an individual but that can affect their biological and psychological functions.

Vibroacoustic disease, induced by long-term exposure to low frequency noise, is a chronic condition broken down into three stages on the basis of symptoms (see Table 1). It is now a well studied phenomenon, and there are a number of human and animal models explaining how low frequency sound can lead to cardiovascular and respiratory disease (Castelo-Branco & Alves-Pereira, 1999/2004). It has been shown that VAD can be caused by an increased production of collagen (a protein that upholds the structural integrity of many bodily tissues), which thickens the media layer of blood vessels and restricts blood flow in exactly the same manner as atherosclerotic plaques.

A study undertaken in Portugal (Alves-Pereira & Castelo-Branco, 2007) compared the sound waves in an abode located adjacent to an industrial complex whose residents were diagnosed with VAD with that in a house in which wind turbines have recently been constructed. The authors of the study concluded that, on the basis of similarities in the sound waves that both houses were exposed to, the residents living around the wind turbines would also develop VAD should they choose to remain in their home. The phenomenon of VAD is supported by correlational evidence coupled with a thoroughly detailed mechanism. However, further research is required to establish the veracity of the approach to human health, but there should be no dismissal of the phenomenon until such research has been undertaken.

Table 1: Progression of vibroacoustic disease (Castelo-Branco & Alves-Pereira, 2004):

Stage 1 - Mild (1–4 years exposure): Slight mood swings, indigestion, bronchitis.

Stage 2 - Moderate (4–10 years exposure): Chest pain, definite mood swings, back pain.

Stage 3 - Severe (more than ten years exposure): Psychiatric disturbances, hemorrhages, ulcers, headaches, decrease in visual acuity, severe joint pain.

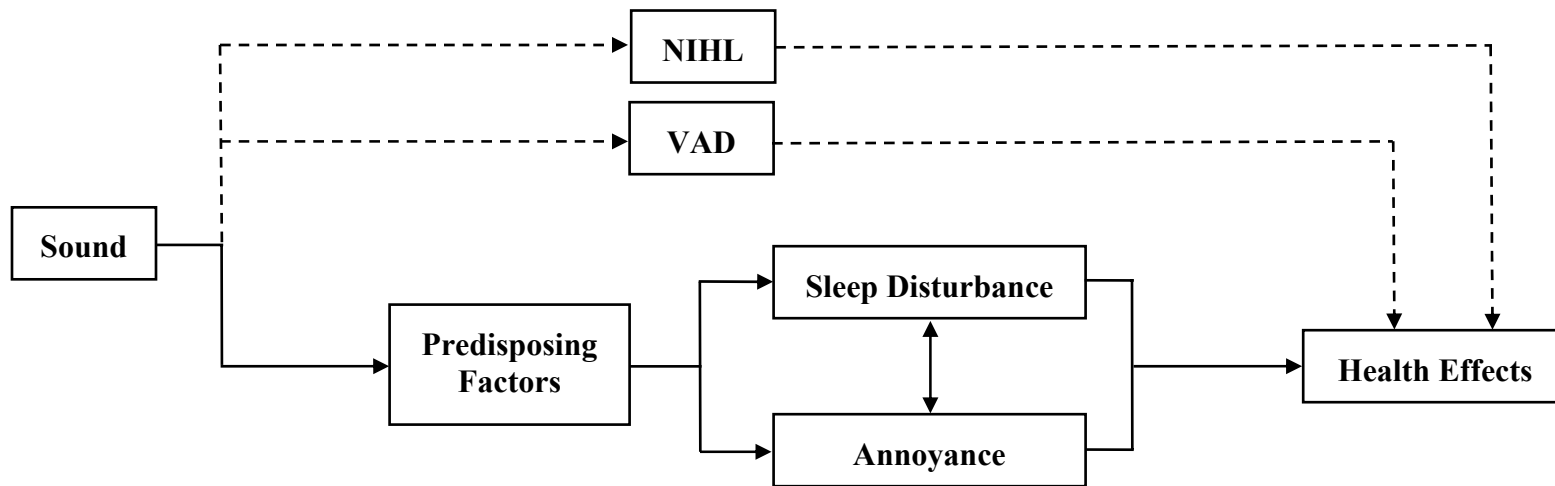


Figure 7: A simple model detailing how noise might compromise health. The dashed lines indicate the author’s classification of the physical effects of noise, while the solid lines represent the non-physical effects of noise.

The non-physical effects of noise

The non-physical effects of noise are defined as noise-induced impairments of health brought about by psychophysiological processes. Psychophysiology is that part of biology that investigates how psychological processes (e.g., anxiety) can influence physiological responses (e.g., respiration rate) and vice versa. With reference to the health literature it appears that two general processes, annoyance and sleep disturbance, can summarise the bulk of the psychophysiological underpinnings of noise-induced health deficits. Each of these two processes will be discussed at length in subsequent sections, but as Figure 7 attests, the two processes are not always mutually exclusive, and there can be interaction between the two.

A defining characteristic of the non-physical effects of noise is the degree of individual differences exhibited within groups exposed to similar levels of community noise. Although individual differences may be found amongst levels of NIHL and noise exposure they are not nearly as pronounced as those found with annoyance and sleep disturbance. Unfortunately for policymakers there is no proportional relationship between annoyance/sleep disturbance and community noise levels, as these outcome factors will be influenced by distinctive characteristics associated with the listener (Flindell & Stallen, 1999). Thus substantial individual differences are expected, and indeed found, when examining the effects of community noise on humans. In order to uncover the factors responsible for the diverse range of responses to noise we need to delve into the black boxes in Figure 6, which has been relabelled “Predisposing Factors” in Figure 7. These factors, which include age, noise sensitivity, attitude, and personality, will be described in greater detail in a subsequent section.

The physical-effects of noise were described as bodily systems exposed to excessive (e.g., NIHL) or chronic (e.g., VAD) acoustic energy. The non-physical effects of noise are caused not by force alone but rather the interplay between sound and an individual’s physiological and/or psychological processes. For the non-physical effects of noise the underlying mechanisms implicated in health degradation stemming from annoyance and sleep deprivation are the stress response and fatigue. Thus, in susceptible individuals annoyance and sleep disturbance may develop into a stress response or fatigue that may in turn lead to symptoms and subsequent disease (Harry, 2007).

The non-physical effects of noise and the stress response

Any object or event that an individual perceives as a threat to their safety or to the resting and restorative characteristics of their living environments can be classified a stressor. Noise is a psychosocial stressor that can induce maladaptive psychological responses and negatively impact physical health via the autonomic nervous system, the neuroendocrine system, and the immune system (these three systems are summarised for the layperson in the Table 2).

Table 2: Three systems implicated in the negative relationship between stress and health

The Autonomic Nervous System

A control system in which the brain manages numerous biological processes based upon the demands of the environment. The autonomic nervous system controls, amongst other processes, heart rate, digestion, respiration rate, salivation, perspiration, diameter of the pupils, urination, and sexual arousal.

The Neuroendocrine System

The system linking processes in the central nervous system (i.e., the brain) to the endocrine system, which releases hormones. The most thoroughly studied neuroendocrine complex, the Hypothalamic-Pituitary-Adrenal (HPA) axis, has been implicated as the chief mechanism in the human stress response.

The Immune System

A collection of bodily structures and processes concerned with the identification, elimination, and disposal of foreign objects (i.e., antigens). Immune systems protect the body from infection, and when compromised, leave an individual vulnerable to disease.

Physiological models already exist to explain the adverse health effects that arise from exposure to community noise. As a stressor, community noise may impact the cardiovascular system through the release of hormones (e.g., cortisol and adrenalin) that directly or indirectly regulate blood pressure, heart rate, and other internal processes (e.g., digestion) via a system known as the Hypothalamic-Pituitary-Adrenal (HPA) axis (see Table 2). The response underlies what is commonly termed the “fight or flight” state, and though it is a vital process in the survival of an organism, it can, if sustained for long periods of time, result in a breakdown of physical and mental health (Selye, 1975). The WHO note (Berglund et al. 1999):

“The risk of adverse health effects must be considered in the light that noise as a stressor may operate through physiological responses modified in complex ways by individual psychological processes”

In medical terms, the pathophysiological basis for a noise-health relationship is likely to be the stimulation of hypothalamus-pituitary-adrenal axis, adrenal medulla, and autonomic nervous system (specifically the sympathetic nervous system) with a subsequent release of stress hormones (e.g., adrenaline, cortisol). In combination with adrenaline, cortisol is the main hormone released when an individual is exposed to a stressor. Stress hormones in themselves are not necessarily bad things, given that they prepare the body for a fight, flight, or freeze response. Cortisol concentrations follow the body’s day/night rhythms, peaking in the morning, and dipping three-to-four hours after sleep onset. A chronic stressor has the ability to disrupt the cortisol cycle, and if maintained, can impair sleep. Furthermore, excessive levels of cortisol lead to compromised immune function, and accounts for the relationship between stress, compromised immunity, and disease.

Noise-induced stress has been shown to directly influence the activity of the human endocrine system, the process that regulates hormone levels in the body. Noise exposure influences the endocrine system by evoking a maladaptive emotional response (i.e., annoyance) or by disturbing sleep. Animal research has demonstrated an association between cortisol levels and noise. Further, excessive cortisol levels in a region of the brain called the frontal lobe results in deficits in cognitive function, including planning, abstract thought, and impulse control (Cui, Wu, & She, 2009). Other studies have demonstrated that the response of the endocrine system to noise can result in disease, including cardiovascular, respiratory, and musculoskeletal pathology (Niemann & Maschke, 2004). These biological responses have long-term health implications including fatigue, lower work productivity, increased proneness to accidents, and disturbances of blood pressure and coronary circulation. Further studies (Enhealth, 2004) have demonstrated that sound, even at levels below the threshold of waking, can affect stress hormone levels:

“There is moderate evidence that chronic noise exposure affects motivation, blood pressure, and hormone secretion.”

Case studies reporting noise-induced symptoms consistent with a stress response around WTI are common. One resident living near a wind turbine in the United Kingdom reports (Harry, 2007):

“Stressed and extremely anxious, as I am constantly disturbed by them when they are turning fast and facing towards me”

The World Health Organisation [LARES] Noise and health study

In 2004 the WHO released the first comprehensive report on the non-physical effects of noise (Niemann & Maschke, 2004). This study determined that chronic noise annoyance, and not noise level, was the best predictor of health risk. The report stated that, of 8325 participants, approximately 25% reported regular noise-induced sleep disturbances, and additionally, that those reporting sleep disturbances were at greater risk of suffering depression, hypertension, and migraines. Moderate annoyance to traffic noise increases the risk of asthma, diabetes, and migraine slightly, and the risk of cardiovascular symptoms significantly. They also report that people reacting negatively to community noise also have a greater chance of developing the symptoms of major depression. For those exhibiting strong annoyance with respect to traffic noise, their annoyance is a risk factor for respiratory symptoms, cardiovascular symptoms, bronchitis and arthritis. The WHO results clearly demonstrate that even though community noise may not be of sufficient magnitude to induce hearing loss it can still be a potent risk to health.

In the [LARES] study the WHO report that moderate annoyance to traffic noise increases the risk of asthma, diabetes, and migraine slightly, and the risk of cardiovascular symptoms significantly. They also report that people reacting negatively to community noise also have a greater chance of developing the symptoms of major depression. For

those exhibiting strong annoyance with respect to traffic noise, their annoyance is a risk factor for respiratory symptoms, cardiovascular symptoms, bronchitis and arthritis, but not skin disease, heart attack, diabetes, or asthma. An investigation examining self-reported health and annoyance due to wind turbine noise supported some, but not all, of these findings (Pedersen & Wayne, 2008). The WHO concluded

“...the results of the [LARES] study confirm increased health risks at chronically strong noise annoyance as well as for noise induced sleep disturbances at an epidemiological level”.

Wind Turbine Syndrome

As we go to press a book entitled “Wind Turbine Syndrome”, authored by Nina Pierpont has been released into the public domain (Pierpont, 2009). Pierpont (2006), MD, PhD, Fellow of the American Academy of Paediatrics and a former clinical professor of paediatrics at the College of Physicians and Surgeons, Columbia University, New York, states:

“Wind Turbine Syndrome is the clinical name I have given to the constellation of symptoms experienced by many (though not all) people who find themselves living near industrial wind turbines: sleep problems (insomnia), headaches, dizziness, unsteadiness, nausea, exhaustion, anxiety, anger, irritability, depression, memory loss, eye problems, problems with concentration and learning, tinnitus (ringing in the ears).”

Pierpont (2009) hypothesizes that wind turbines may affect the vestibular system, which plays an important role in the maintenance of balance. The vestibular system works in conjunction with other bodily systems to maintain balance, coordinating with the visual system and the proprioceptive sense (messages from muscles). Wind turbines may compromise the system in two ways: first, by the visual disturbance of the moving blades and shadows (i.e., the ‘flicker’) and second, by direct vibration of the vestibular system. Such a model would explain why residents in the proximity of wind turbines complain of vertigo, dizziness with nausea, and migraines (Pierpont, 2006). Residents living near wind turbines regularly report headaches and migraines induced by turbine noise. What follows are quotes from Harry’s (2007) study on the health effects of wind turbines:

“I get headaches frequently especially when the turbines are running at a fast rate towards us”

“I get headaches and thumping in the ears. I also find its continual noise very distressing”

“Suffer with headaches more and feel tired more so find daily tasks difficult to do”

Wind Turbine Syndrome awaits further validation from the medical establishment, but the book itself has undergone peer review and presents compelling evidence of adverse health effects arising from WTI sound. The next phase of research will require

establishing a cause-and-effect relationship between WTI sound and vestibular function. If such a relationship is found then the veracity of Wind Turbine Syndrome will be confirmed. Pierpont's work is discussed in later sections.

9. NOISE, ANNOYANCE AND HEALTH

From a psychological perspective chronic exposure to community noise can impact health through information overload, over arousal, loss of coping strategies, loss of privacy, and loss of perceived control. These mechanisms give rise to a number of subjective responses to noise, of which the most common is annoyance. Noise annoyance is a reflection of an impaired quality of life, has an adverse effect on health (Pedersen & Persson Waye, 2007) and can be considered a psychological stressor (Maris et al., 2007). The WHO (Niemann & Maschke, 2004) reports that noise annoyance can express itself through malaise, fear, threat, uncertainty, restricted liberty, excitability, or defencelessness. Furthermore, annoyance may be underwritten by fear and anger, especially if one believes that they are being harmed unnecessarily. A study in Australia (Brisbane City Council, 2003) reported that of those claiming to be seriously annoyed by noise, approximately ten percent reported becoming excessively aggressive due to the impact of the noise. Research informs us that unwanted sound can be bothersome and becomes a social problem when the noise is man-made.

Defining Annoyance

Before exploring noise-induced annoyance in more detail, some consideration should be given to the definition of annoyance, as there are explicit differences between the everyday usage of the term and the medical usage of the term. The word annoyance is often misinterpreted by the general public as a feeling brought about by the presence of a minor irritant. The medical usage, in contrast, exists as a precise technical term and defines annoyance as a mental state capable of degrading health.

An example of one definition of noise annoyance, formulated by the European Commission's noise team (European Union, 2000), is:

“Annoyance is the scientific expression for the non-specific disturbance by noise, as reported in a structured field survey. Nearly every person that reports to be annoyed by noise in and around its home will also experience one or more of the following specific effects: Reduced enjoyment of balcony or garden; When inside the home with windows open: interference with sleep, communication, reading, watching television, listening to music and radio; Closing of bedroom windows in order to avoid sleep disturbance. Some of the persons that are annoyed by noise also experience one or more of the following effects: Sleep disturbance when windows and doors are closed; Interference with communication and other indoor activities when windows and doors are closed; Mental health effects; Noise-induced hearing impairment; Hypertension; Ischemic heart disease.”

Though not all would agree with the above definition. Acoustics expert Kamperman and James (2008) argue a distinction between annoyance and disturbance, where annoyance is a mental state and disturbance an insult to one-or-other physiological processes. For this reason it makes no sense to talk about “sleep-annoyance”, nor to define annoyance itself as a disturbance. Dr Alice Suter (1991) likewise has reservations about the usage of term annoyance:

"Annoyance" has been the term used to describe the community's collective feelings about noise ever since the early noise surveys in the 1950s and 1960s, although some have suggested that this term tends to minimize the impact. While "aversion" or "distress" might be more appropriate descriptors, their use would make comparisons to previous research difficult. It should be clear, however, that annoyance can connote more than a slight irritation; it can mean a significant degradation in the quality of life. This represents a degradation of health in accordance with the World Health Organization's (WHO) definition of health, meaning total physical and mental well-being, as well as the absence of disease."

Both the physical nature of the sound and the psychological characteristics of the listener combine to produce noise annoyance. It is generally agreed that a physical threshold exists that, when exceeded, almost totally determines the levels of annoyance elicited by noise. Below this threshold however, other psychological-based factors come to the fore (Berglund & Nilsson, 1997; Pedersen & Persson Waye, 2007). A detailed analysis of what factors induce an annoyance response to sound will now be undertaken.

WHAT DETERMINES ANNOYANCE?

While there is a strong correlation between the sound pressure level (i.e., amplitude) of a sound wave and the perceived loudness of a sound, there is no clear relationship between sound pressure level and the psychological responses that individuals have to a sound. Annoyance can partly be related to the physical characteristics of a sound, including amplitude (i.e., loudness), frequency (i.e., tonal characteristics), and how the sound changes across time (called “dynamics”). For example, intermittent, irregular, tonal, pulse or rhythmic sounds are associated with greater annoyance reactions than steady-state continuous sound of uniform amplitude. However, many nonacoustical factors determine how annoyed one will become towards a source of community noise (Kuwano & Seiichiro, 1990; Nosulenko, 1990; Johansson & Laike, 2007; Nelson, 2007). Degrees of annoyance to noise cannot be measured by acoustical equipment such as sound level meters; instead it can only be described by the listeners themselves. Thus, the response of the individual to the sound is just as important as the acoustic properties of the sound wave. The “people” side of noise is commonly absent from acoustics reports, where acousticians have a tendency to treat a spectrum analyzer or a free field microphone as equivalent to a human being. It is for this reason that a number of quotes from real people experiencing real turbine noise have been included within the body of this work.

PHYSICAL FACTORS

The unique spectral characteristics that wind turbine sound possesses are easily perceptible. In wind turbines there are two sources of noise: mechanical and aerodynamic. The former relates to noise generated by the mechanical components of the turbine's generator and control systems. The latter noise, aerodynamic noise, originates from the airflow around the turbine blades, and its level increases with the speed of the blades. Mechanical noise is largely masked by aerodynamic noise, and it is aerodynamic noise that elicits an annoyance response from listeners (Pedersen & Persson Waye, 2007). The acoustic origins of sound will now be explored in relation to noise annoyance.

Noise Level and annoyance

Noise level is in part correlated with the psychological effects of wind turbine noise, however, it is not uncommon for people to judge lower level turbine noise as more annoying than higher turbine levels (Nelson, 2007). Harry (2007) collected data from a number of residents living in the vicinity of wind turbines, and noted that noise annoyance from wind turbines was found at lower sound pressure levels than in studies from road traffic noise, supporting previous research (Pedersen & Persson Waye, 2004). However, as a general rule, it is true that as the sound level of turbines increase, so too does the *probability* that annoyance will increase, but there will be substantial variation between individuals. Additionally, the taller the turbine the more intense the emitted sound waves, though again the literature indicates that so long as the energy is audible then its impact on nearby residents will not be predicted on the basis of level alone.

It should also be noted that overall measures of sound level are not in themselves useful in predicting annoyance if those levels are dynamic (i.e., they change over time). van den Berg (2004) has shown that wind turbines produce noise that has an impulse character. Because wind is variable and not constant, the nature of wind turbine noise and its corresponding level are also variable and inconsistent. Human senses act as change detectors, or contrast detectors, responding to changes in sound rather than to the absolute level of the sound itself. In technical jargon the sensation of sound is said to be differentially coupled to the physical stimulus. Furthermore, we are more sensitive to change in continuous noise (such as impulsive turbine noise) than to discrete auditory events (e.g., a dripping tap at night). Thus wind variability will bring about noticeable changes in the level of turbine noise, irrespective of the overall level of that noise, and the changes in level of turbines due to fluctuations in wind speed will make the noise more noticeable, especially so at night.

This is, of course, not to say that level is not important, far from it. However, what needs to be accepted is that level is only *one* of *many* important variables. For example, a recent study by van den Berg et al (2008) reported that of participants who did not benefit economically from wind turbines, approximately 30% reported that they were rather or very annoyed at sound levels between 30 and 40 dB(A), and furthermore:

“Respondents who reported that they were annoyed by wind turbine sound were more likely to be psychologically distressed, reporting symptoms of stress and having

difficulties falling asleep. It appears that these symptoms occur when people are annoyed, but it does matter at what sound level this annoyance occurs”

Another important factor associated with sound level is the range of levels, that is, the minimum and maximum levels that are emitted by a noise source. Noise measures based on energy summation and expressed as averaged values are not sufficient when examining the health-related effects of noise. The WHO has repeatedly emphasised the importance of measuring the maximum values of the noise fluctuations (Berglund et al. 1999). Thus, any levels reported by acoustic experts must be accompanied by measured (or predicted) maximum levels. Determining acceptable noise levels based on averaged levels lacks rigour and validity, and has the potential to put the public at risk.

Low Frequencies and annoyance

Noise containing lower frequency components generally elicits stronger negative evaluations than noise that does not. Research has shown that low frequency noise increases cortisol levels in those who are sensitive to noise (Persson et al., 2002), and has the ability to interfere with cognitive processes. That noise consisting of low frequency components can induce stress in the listener has been known for some time, and such noise is currently being applied in some countries to manage unruly crowds. The WHO (Berglund et al. 1999) state:

“It should be noted that a large proportion of low-frequency components in noise may increase the adverse effects on health ... It should be noted that the low frequency noise, for example, from ventilation systems, can disturb rest and sleep even at low sound pressure level...Special attention should be given to: noise sources in an environment with low background sound levels; combinations of noise and vibrations; and to noise sources with low-frequency components.”

And further:

“The evidence on low frequency noise is sufficiently strong to warrant immediate concern...Health effects due to low frequency components in noise are estimated to be more severe than for community noises in general”

But does the acoustic energy emitted from wind turbines contain low frequency components? In relation to turbines there is extreme controversy as to whether low frequencies (less than 20 Hz) are present, and this matter will be left for the acousticians to argue. British acoustician Dr Geoff Leventhall makes the claim that because wind turbines don't produce low frequencies, then people can't hear them, and therefore they are making up their complaints. Contrastingly, Dr van den Berg (2004), another widely recognised expert on wind turbine sound emissions, states that turbines do indeed emit low frequency vibrations, though it is not clear as yet how these frequencies contribute to noise annoyance. Let us bypass the acousticians entirely and instead examine statements from individuals residing in the vicinity of turbines. Here is a statement from a British resident living near a wind turbine (Harry, 2007):

“Tired, disturbed by noise. Feel it as much as hear it. Developers deny there are any problems unless we can prove it, but how can we do that?”

The description of “feeling” rather than hearing the sound is an indication that low frequencies are present. Lower frequencies correspond to the resonating frequencies of our body organs, and in their presence encourage them to vibrate. For example, the head resonates at 20 – 30 Hertz and the abdomen 4 – 8 Hertz. A study examining the chronic effects of low frequency vibration and subsequent psychological and physiological consequence are reported in Table 3 (Rasmussen: Cited in Harry, 2007). In fact, the weight of opinion supports the claim that low frequency noise is produced by wind turbines, with the displacement of air by the blades and the turbulence around the blade surface the likely cause. These low frequencies can produce a seismic characteristic leading to those in the proximity of wind turbines to complain not only of audible noise but also noise that they can feel (Harry, 2007). Low frequency sounds modulate the perception of other audible frequencies and can be sensed as a vibration of the chest or throat. Residents neighbouring wind turbines in the USA have described (Pierpont, 2006):

“distressing sensation of having to breathe in sync with the rhythmic thumps of the turbine blades, especially at night when trying to sleep”.

Table 3: psychological and physiological sequelae resulting from low frequency vibration.

<u>Frequency of vibration</u>	<u>Symptoms</u>
4 – 9 Hz	Feelings of discomfort
5 – 7 Hz	Chest pains
10- 18 Hz	Urge to urinate
13- 20 Hz	Head Aches

Casella (2001), reporting on the effects of low frequency turbine noise, makes the observation that, compared to medium and high frequencies, low frequencies levels decay slowly with distance, are less attenuated by conventionally designed structures, cause certain building material to vibrate, and can sometimes resonate with rooms and thus undergo amplification. The relationship between low frequency wind turbine noise and building type creates an interesting proposition in which the low frequency sound may be louder inside the house than out. As the engineering experts attest (Kamperman & James, 2008):

“Modern home construction techniques used for most wood frame homes result in walls and roofs that cannot block wind turbine low frequencies from penetrating into the interior....When low frequency sound is present outside homes and other occupied structures; it is often more likely to be an indoor problem than an outdoor one. This is very true for wind turbine sounds.”

Overall characteristics of the noise

The overall spectral characteristic of the noise is also important in determining any subsequent psychological response. A number of studies have reported that aerodynamic noise can be perceived in different ways, subjectively described as lapping, swishing, whistling, roaring, humming, and thumping. One study reports that up to 25% of people who could hear aerodynamic noise from their dwellings were annoyed. In the same study a strong association was found between annoyance and a 'swishing' sound (Pedersen & Persson, 2004), but that pulsating or throbbing noises were not significantly related to annoyance. In relation to wind turbines, amplitude-modulated noise is judged more annoying than continuous noise, as Pedersen et al., (2007) report:

"The most annoying noises were predominantly described as "swishing", "lapping" and "whistling". These could all be seen as being related to the aerodynamic sound and as descriptions of a time-varying sound"

The most recent wind turbine study examining the effects noise conforms to these previous findings (van Den Berg et al. 2008):

"The 'swishing' character of the wind turbine sound was in the study found to be the most annoying of the suggested sound properties. 'Swishing' is a description of an amplitude modulated sound that is pulsating with the pace of the rotation of the blades. Three out of four participants declare that swishing or lashing is a correct description of the sound from wind turbines. Perhaps the character of the sound is the cause of the relatively high degree of annoyance. Another possible cause is that the sound of modern wind turbines on average does not decrease at night, but rather becomes louder, whereas most other sources are less noisy at night"

Thus it can be concluded on the basis of these studies that the overall character of the sound, and not just its level or loudness, need to be taken into account when predicting annoyance.

Physical Moderators: Distance, weather, and terrain

Further physical factors that influence annoyance responses including the proximity of the turbines, atmospheric conditions, and the immediate terrain in which the turbines are located.

Adverse psychological reaction to wind turbine noise have been reported for individuals living between 300 meters and two kilometres of turbines (Harry, 2007), though annoyance decreases as distance increases (Pedersen & Persson, 2004). However, much research is still needed to determine what constitutes a 'safe' distance from a WTI or turbine (Alves-Pereira & Castelo Branco, 2005):

"Instead of attempting to appease those who are vehement about the notion the wind turbine are inconsequential to human health, and to avoid the useless acrimonious debate

that usually ensures after these type of data are presented, a challenge is offered up: zoning laws. And this immediately leads to the issue of safe distances from aerodynamic pressure waves produced by rotating wind turbine blades.”

Two medical practitioners have offered what they believe to be safe distances between wind turbines and dwellings, based on medical evidence. Dr. Harry (2007) from the United Kingdom proposes 1.5 miles (2.4 kilometres) and Dr Pierpont from the United States has independently confirmed this distance of 1.5 miles (Pierpont, 2006). But other opinions exist in the literature. The insufficient research conducted on the health effects of wind turbine noise have resulted in the French Academy of medicine (FAoM, 2006) recommending halting wind turbine construction closer than 1.5 km from residences. The British Noise Association (2009) gives a similar guideline with regards the distance between wind turbines and dwellings: 1 mile. The WHO states:

“Precautionary measures regarding the placement of wind turbines near inhabited buildings are justified. Safe distances between wind turbine rotating blades and inhabited buildings have not yet been determined by the scientific community. It follows until scientific data exist on the subject, no credible claims can be made regarding safe distances.”

The importance of atmospheric conditions in relation to annoyance and wind turbine noise has been established. People are more likely to notice and be annoyed at wind turbine noise when the wind was blowing from the turbines towards their homes, or on hot summer nights (Pedersen & Persson, 2004). Harry (2007) states:

“The effect is stronger at night because in the stable atmosphere there is a greater difference between rotor average and near tower wind speed. In addition the multiple turbines can interact with each other to further multiple the effect.”

And from another source (Pedersen & Persson, 2007):

“The observed frequency of annoyance at low sound pressure levels in the Swedish studies could furthermore be due to atmospheric situations influencing large modern wind turbines more than the older ones – leading to higher sound exposure than accounted for in the planning process”

Finally, it has been suggested that mountainous areas may allow low frequency noise to travel further which may explain the long distance over which the turbines can be heard. Those in rural areas living on complex terrain are more likely to notice wind turbine noise than others (Pedersen & Wayne, 2008), and it has been reported that living on flat ground decreases the likelihood of hearing wind turbine noise (Pedersen & Persson, 2007).

PSYCHOLOGICAL FACTORS

Up to this point it has been argued that the non-physical effects of noise cannot be explained solely by the physical properties of the acoustic stimulus. As WHO state (Berglund et al., 1999):

“However, annoyance reactions are sensitive to many nonacoustic factors of a social, psychological, or economic nature, and there are considerable differences in individual reactions to the same noise exposure”

Table 4 lists, in no particular order, the nonacoustic factors found to influence levels of noise annoyance that were uncovered by Flindell and Stallen (1999). The following discussion draws on a number of these factors and others besides, including demographics and pre-existing mental illness, and discusses how they relate to annoyance.

Table 4: Factors influencing the degree of annoyance to noise (from Flindell and Stallen, 1999).

- Perceived Predictability of the noise level changing
- Perceived control, either by the individual or others
- Trust and recognition of those managing the noise source
- Voice, the extent to which concerns are listened to
- General attitudes, fear of crashes and awareness of benefits
- Personal benefits, how one benefits from the noise source
- Compensation, how one is compensated due to noise exposure
- Sensitivity to noise
- Home ownership, concern about plummeting house values
- Accessibility to information relating to the noise source

Gender

The published research conducted on the relationship between community noise and health indicates that the adverse effects of community noise on health are independent of gender (Pedersen & Persson, 2004; Pedersen & Persson, 2007; Niemann & Maschke, 2004; Miedema & Vos, 1999). The independence of gender on annoyance has been found using samples of over 60,000 individuals (van Gerven, 2009). However, not all agree with this finding, and Dratva (2010) found in a Swiss study that women reported significantly higher degrees of noise annoyance than men. An American study (Rhudy & Meagher, 2001) reported that, compared to adult males, women are more likely exhibit noise-induced stress.

Ethnicity

No data has been reported in the peer-reviewed literature addressing the influence of ethnicity on noise annoyance.

Socio-economic status

There are no reports of a relationship between socio-economic status (Niemann & Maschke, 2004) and noise-induced annoyance, though those in high deprivation areas are more likely to be close to noise generators (e.g., airports) than those in low deprivation areas. Likewise, there are no reports of a relationship between educational achievement and annoyance (Miedema & Vos, 1999).

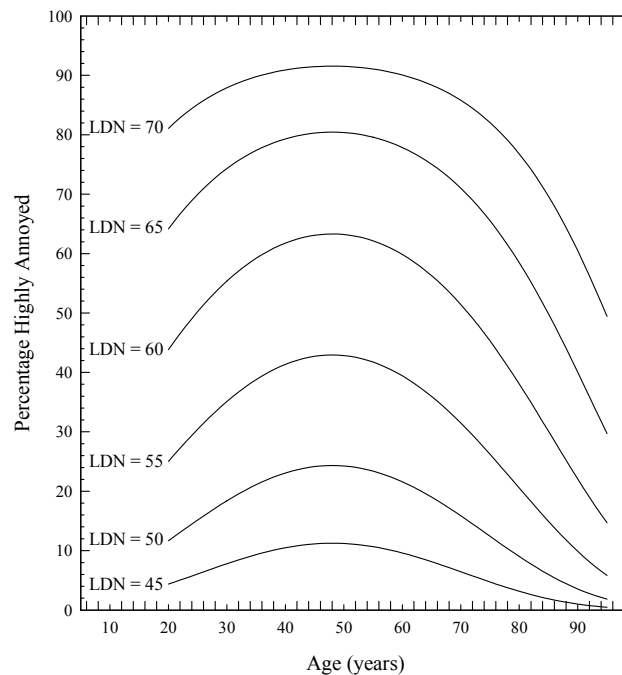


Figure X: Noise annoyance as a function of age

Age

An interesting “U”-shaped relationship has been reported between age and noise annoyance (van Gerven et al. 2009). An international analysis of over 60,000 individuals aged 15 years onwards uncovered a peak in noise annoyance at age 45. This finding could not be related to noise sensitivity (discussed below) and was independent of noise level.

Other research suggests that children (EnHealth, 2004) in particular suffer attentional deficits that actually improve performance on simple tasks but greatly degrade performance on complicated tasks (Berglund et al., 1999). Chronic exposure to noise has been reported to retard reading skills and reduce motivational capabilities in children, and

to instil them with greater feelings of helplessness (Berglund et al., 1999). Interestingly though, these effects on children may not be related to an actual annoyance response.

Noise sensitivity

The subjective experience of annoyance is a common reaction to noise. Different individuals can exhibit different annoyance reactions to the same noise, and these individual differences can be ascribed to differences in noise sensitivity. It has been concluded that noise sensitivity has no relationship to hearing acuity, and instead reflects a judgmental, evaluative predisposition towards the perception of noise (IEH-MRC, 1997). Furthermore, research has shown that noise annoyance reactions are mostly determined by a person's sensitivity to noise (Zimmer & Ellermeier, 1999; Miedema & Vos, 1999/2003). A formal definition of noise sensitivity has appeared in the literature. Dr Stephen Stansfeld (1992), a psychiatrist, defines noise sensitivity thus:

“In summary, noise sensitivity may be compromised of two elements. Noise is important to noise-sensitive people who attend to noise more, discriminate between noise more, and tend to find noises more threatening and out of their control than people who are not sensitive to noise. Secondly, because of negative affinity, they react to noises more than less sensitive people, and may adapt to noises more slowly. This may result in a greater expression of annoyance to noises than in less sensitive people.”

The accepted view is that sensitivity to noise can be considered a stable personality trait, and as such an individual's tolerance to peripheral sound is measurable on a continuum. Research in the last decade has demonstrated that individuals report a wide range of different responses to noise ranging from highly tolerant to highly sensitive, though the basis for these individual differences are understudied and poorly understood. A nontrivial number of individuals are noise sensitive, and suffer impaired health as a result. It has been estimated that noise sensitive individuals make up approximately 15% of the general population, and more so in certain clinical populations (e.g., brain injury, dyslexia, schizophrenia, autism). Noise-sensitive individuals characteristically suffer from noise-induced irritability, stress-related disease, headaches, and poor sleep, all of which strongly negate good health and quality of life. With increasing levels of community noise it is important that the phenomenon of noise sensitivity be clearly described and explained in both clinical and non-clinical populations.

One New Zealand study has reported that approximately 15% of individuals from a large sample of Pacifica people living in Auckland, New Zealand, were severely disturbed by noise in their neighbourhood (Carter et al., 2009). Recent epidemiological research undertaken in the proximity of the Auckland International Airport (Mathews, 2009) indicated that approximately 18% of the sample was extremely noise sensitive, which is equivalent to the few estimates published in international studies. Further physiological studies undertaken in the author's laboratory using a convenience sample ($n=100$) of university students and academics, identified approximately 16% of subjects as highly noise sensitive.

Noise sensitivity has a large impact on noise annoyance ratings, lowering the annoyance threshold by 11 dB (Miedema & Vos, 1999). Furthermore, there is an interaction between noise level and noise sensitivity. Annoyance scores increase rapidly as noise level increases for those sensitive to noise, whilst it stays relatively flat for those insensitive to noise (Miedema & Vos, 2003). Research also informs us that noise sensitive individuals are particularly vulnerable to low frequency noise. For example, it has been shown that in noise sensitive individuals the introduction of low frequency noise can boost salivary cortisol levels (Persson et al. 2002). However, while there is a strong correlation between noise sensitivity and annoyance there is a weak correlation between noise sensitivity and noise level (Miedema & Vos, 2003):

“Noise sensitivity changes the influence of noise exposure on noise annoyance, and does not only have an additive effect, i.e., it affects the rate at which annoyance increases when noise exposure gets higher. It also alters reactions other than noise annoyance, such as self-reported sleep disturbance attributed to noise”

Some clinical populations experience more severe annoyance reactions, characterised by a complete loss of functional ability in the presence of noise. A large number of psychological disorders (e.g., dyslexia) and injuries (e.g., traumatic brain injury) include noise sensitivity as a debilitating symptom. Thus there is compelling evidence that noise sensitivity maybe determined more by biological processes than social factors. There are few studies have investigated the biological basis of noise sensitivity, though genetic studies using monozygotic (i.e., identical) and dizygotic twins suggest that noise sensitivity has a heritability of 40% (Heinonen-Guzejev et al., 2005). Furthermore, the onset of noise sensitivity in over a third of traumatic brain injury survivors likewise points to a biological basis (Dischinger et al., 2006). A solitary brain imagining study (Pripfl et al, 2008) investigating noise sensitivity showed sensitive individuals had distinct patterns of brain activity that distinguished them from non-sensitive individuals. They concluded that differences in noise sensitivity most likely reflect different cognitive strains. These results concur with previous results suggesting that noise sensitive individuals do not only evaluate a noisy situation as more annoying but experience higher levels of cognitive strain (e.g., Sandrock, 2009).

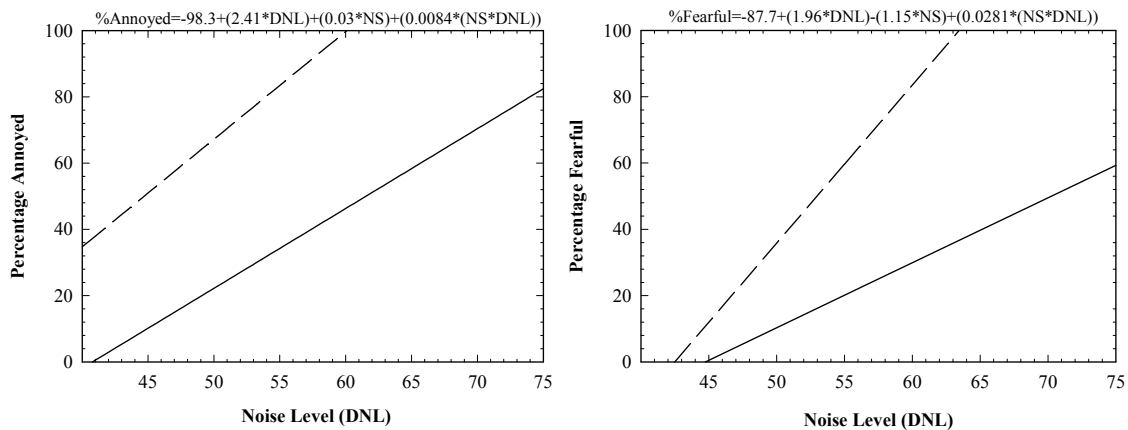


Figure X : Caption here...

Feelings of Intrusion and Loss of Privacy

Another subjective response to noise is the feeling of violation and intrusion, caused by an acoustic invasion that disregards one's personal boundaries. Individuals may elicit a fear response to an undesirable noise that is encroaching in their environment. Such a response may emerge from specific concerns about the safety of the noise and its source, and that levels of fear correlated with levels of annoyance (Job, 1988). As Burglund et al, (1999) states:

“An intrusive sound is very difficult to ignore, even if one so wishes”

and in relation to turbines Pedersen (Pedersen & Waye, 2008) comments:

“Sounds that are easily perceived and difficult to filter out would be perceived as intrusive ... Turbines are placed mainly in rural areas with low ambient sound pressure levels and in an environment where the intrusion of the sound can be expected to be high”

In respect to the restorative value of the home and the intrusion of wind turbine noise, Pederson and Persson (2007) state:

“Expecting the home and its surroundings to be a suitable place for rest and recreation could conversely lead to an appraisal of the sound as threatening personal values. The sound was described as an intrusion into privacy that changed the image of a good home.”

Locality and Lifestyle

Community setting is also a determinant of annoyance. There is an expectation of “peace and quiet” when living in a rural area, and most choose to live in rural areas as they are bastions of tranquillity (Schomer, 2001). A rural area is defined as an area with a population density less than 500 people per square kilometre. The literature shows that those who live in rural areas have different expectations regarding community noise compared to those living in suburban, urban, or industrial areas. People expect rural areas to be quieter, and consequently exposure to community noise will produce a greater negative reaction in rural areas than other areas (Pedersen & Persson, 2004; Willits, 1991). One study reports (Davis, 2007):

“Respondents who were fairly or very annoyed by wind turbine noise more commonly lived in rural areas than in suburban areas in comparison to other respondents”

If a proposed WTI encroaches rural and semi-rural areas populated by residents with a greater expectation for, and value on, peace and quiet, the reaction to the proposed wind turbines is likely to be negative. Amenity values are based upon what people feel about an area, its pleasantness, or some other value that makes it desirable place to live. Noise affects individuals and communities by modifying the extrinsic and intrinsic nature of the environment that attracts and holds people to the locality. Typically, noise can be quantified by sound exposure levels or audibility and qualified in terms of unwanted, annoyance, or loss of amenity. Immediate and long-term effects of noise can affect amenity and impact upon the responses of a “reasonable person”, to the point where they become “forced emigrants”. Because attitudes towards the noise source influence annoyance, then these rural residents are likely to be more annoyed than those living in suburban or urban neighbourhoods (Pedersen & Persson, 2007):

“...exposure from wind turbines would be more negatively appraised in an area that is perceived as unspoiled than in an area where several human activities take place ... People choose environments that harmonise with their self-concept and needs, and that they remain in places that provide a sense of continuity. When a new environmental stressor occurs, the individual’s relationship with her or his place of residence is disrupted. Such a distortion could possibly predispose for an increased risk of annoyance.”

A Scandinavian study on wind turbine noise and annoyance conducted in a rural area reported that fifty percent of respondents described themselves as rather or very sensitive to noise (Pedersen & Persson, 2004). This value contrasts with those estimated in urban areas (approximately 20%) and suggests that noise sensitive individuals seek out rural areas for their lower levels of noise. The same report indicated that annoyance was most frequently reported when participants were relaxing outdoors or on “barbecue nights”. Other commentators support this conclusion (Davis, 2007). It can be embarrassing living near sources of community noise, and there is a public stigma that only those in the lower socio-economic bracket live in the vicinity of noise generators. Such feelings discourage residents from inviting guests around to their houses, and community noise has been shown to interfere with rest and recreational activities (Berglund et al., 1999; Pedersen & Waye, 2008).

Personality

Personality is described as a continuously evolving set of characteristics that influence how a person will think about, and behaviour, in a particular situation. An example of a personality characteristic is extraversion, in which an individual continuously seeks external stimuli and acknowledgment from others in order to gratify their needs. Another example is neuroticism, which describes individuals who are overly anxious or emotional, and are predisposed to adverse reactions when confronting stressors.

People's evaluations of noise differ widely, and in part annoyance may be influenced by the personality characteristics of the individual. As Nelson (2007) puts it:

“It is likely that a great deal of this variation is due to individual personalities and experiences”

Some have argued that noise sensitivity is a personality trait related to, or even subservient to, neuroticism (Miedema & Vos, 2003; Schutte et al, 2007). Belojevic et al. (1997) conducted a study to identify the relationship between personality factors and subjective reactions to noise in a sample of 413 residents in Belgrade. Their results indicated that there was a strong link between neuroticism and noise annoyance. It was concluded that those individuals with high levels of neuroticism are likely to be prone to long-term negative psychological effects of environmental noise (Belojevic et al., 1997). It has also been reported that noise exposure during sleep can lighten the level of sleep in those individuals who are neurotic-introversion personality type (Westman & Walters, 1981).

Disempowerment vs. Control

Reactions to community noise are also mediated by how isolated the individual feels in relation to the decision making processes effecting the noise source, with individuals reporting a sense of disempowerment also reporting higher levels of annoyance. Annoyance coupled by a sense of disempowerment can lead to intense emotional responses that directly impact on the endocrine system. The endocrine system can, in turn, respond by releasing cortisol and other 'fight-or-flight' hormones that then amplify an emotional response. An individual can then get caught in a vicious cycle, compounded by an inability to sleep due to worry, which itself induces a release of cortisol by the endocrine system. In the most recent study on wind turbine noise van den Berg and colleagues (2008) stated, on the basis of their data, that control was a major factor in the human response to turbine noise:

“Respondents that benefit will usually have more control: most or all of them have taken part in the decision to put up the turbines and they can stop them if they want. One respondent remarked that if a turbine close by caused too much noise for him or his neighbour, he stopped the turbine.”

Fear and anger rise when a person feels that they no longer have control of their environment, stress results, and if chronic, feelings of disempowerment will gradually give way to feelings of depression, low self-worth due to an inability to control the noise, and further stress (Maris et al, 2007). The resulting sense of fear that people experience when they feel a lack of control can significantly impact their reports of noise annoyance. One study found that feelings of fear towards the noise source lowered the annoyance threshold by 19 dB (Miedema & Vos, 1999). A Swedish study (Pedersen & Persson, 2007) reported that, for respondents who were annoyed by wind turbine noise, feelings of resignation, violation, strain, and fatigue were statistically greater than for respondents not annoyed by wind turbine noise. Pedersen et al., (2008) state:

“Other factors that would influence the response to noise sources are the opinion of the necessity and the controllability of the noise source”

Belittlement, and a lack of sympathy and respect from WTI developers further exacerbate feelings of disempowerment.

Attitude

Attitudes are defined as a stable pattern of belief, emotional response, and behavioural reactions towards other people, object, events, or issues. Attitudes involve some form of evaluation, either positive or negative, and vary from person to person. Factors such as fear of the source of the noise, feeling that noise annoyance is preventable (Miedema & Vos, 1999), the belief that the authorities can control the noise, the belief that the noise source is not important all have an impact on an individual's reaction to noise and subsequent annoyance levels (Fields, 1993; Lam et al., 2009).

Attitudes towards wind turbines and their operators are related to perceived annoyance (Pedersen & Persson, 2007). The conduct of WTI developers directly influences attitudes towards turbines and their noise. It has been a reoccurring theme in both the literature (Maris et al., 2007; Katsuya, 2002) and submission processes as to whether developers can be trusted by the general public. When the developers lose credibility in the eyes of the public then annoyance responses will be greater. Additionally, those with little personal experience of wind turbines are less likely to judge wind turbines and turbine noise as more negative than those who have them in their daily lives. Those who are assessed with having negative attitudes are more likely to be annoyed by noise (Pedersen & Persson, 2004/ 2007):

“The subject's personal values relating to the living environment appear to influence how the noise from the wind turbines were perceived”.

van den Berg et al, (2008) notes that annoyance is also related to economic factors (see Figure 5 above), and present data showing that those who benefit economically from wind turbines are on average less annoyed than those who do not. Such findings concur with studies examining attitudes towards other sources of electricity generation, in which the perception of benefit (i.e., economic advantage) and generating efficiency is a major

predictor of attitude (Katsuya, 2002). A New Zealand study (Wild, 2008) on public attitudes to WTI identified a substantial number of residents with negative attitudes on account of continual turbine breakdowns and the high levels of maintenance required. Additionally, many respondents complained of the uneven spread of benefits of WTIs, and a lack of local of benefits. The same study showed that, for people living within five kilometres of the turbines, attitudes towards the WTI become more negative following the operation of the turbines (see Figure 8). This trend was not observed with those living between 5 – 15 kilometres, and one can speculate that noise was a factor in this change.

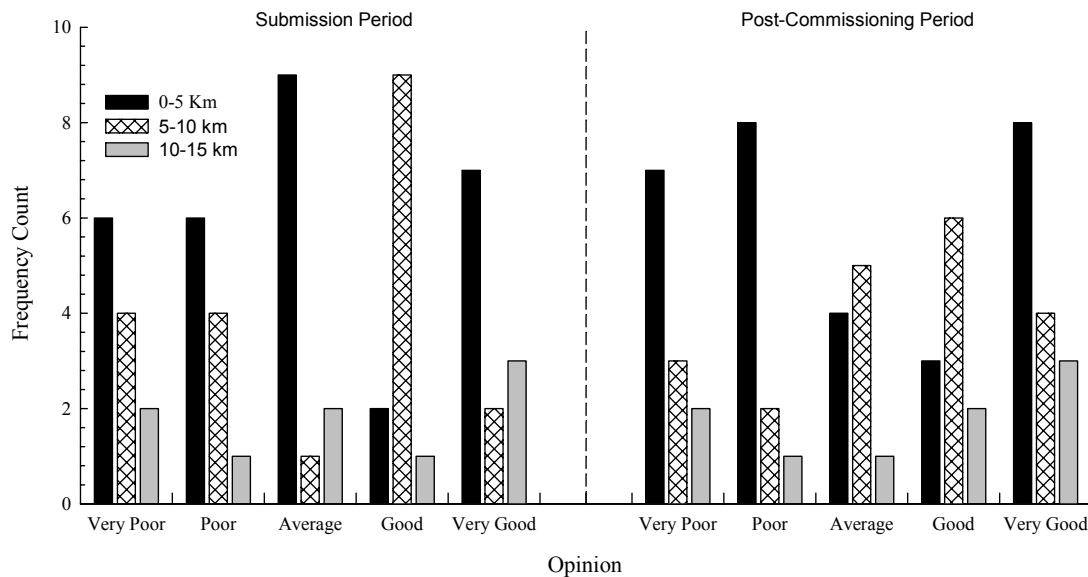


Figure 8: Attitude towards a WTI, before and after operation, categorised by distance from place of current residence (*after Wild (2008), p. 135*).

Visual Impact

The visual impact of the turbines can also influence annoyance levels (Pedersen & Persson, 2004/2007; Johansson & Laike, 2007), probably because the visual presence of the turbines can act as reminders of the negative effects that they have had on people’s lives. In a Danish study, the position of the listener (on a flat landscape) relative to the wind turbine influenced their perception of the noise more than the overall level of the turbine’s noise (Pedersen & Nielsen, 1994). The authors of a Swedish study (Pedersen & Persson Waye, 2008) reported:

“Wind turbines were described as environmentally friendly, necessary, but also as ugly... Seeing a wind turbine in an otherwise non-industrial environment may reduce the individual’s perception of the naturalness of the area and reduce the perception of restoration possibilities.”

Pedersen and Persson Waye (2004) hypothesize that, from an aesthetic perspective, those who view the wind turbines as ugly are likely to disassociate them from the landscape, and as a consequence, feel more annoyed by the turbine noise (Pedersen & Persson, 2004). Other studies (Delvin, 2007) have likewise reported that, as a whole, wind turbines are viewed as eyesores and visual spoilers of the environment (see Figure 9), while some claim that the “flickering” effect of turbines and the motion of rotating shadows lead to headaches and vertigo (Pederson , 2005; Pierpont, 2006). A resident near a turbine in the United Kingdom comments (Harry, 2007):

“Quality of life has disappeared. No longer able to relax in the garden. Glinting and reflection all cause a disturbance. Visual dominance is very oppressive – extremely angry.”

van den Berg et al. (2008) report, on the basis of their results:

“The enhanced probability for annoyance if the wind turbines were visible could also be due to a multimodal effect; the rotating blades of a wind turbine attracting the sight could increase awareness of the sound and hence also the possibly of noise annoyance”.



Figure 9: A cartoon poking fun at WTI developers (here Meridian energy) and NIMBYs (Not In My Back Yard) alike (from www.stuff.co.nz).

Mental Health

In a 2008 WTI consent hearing held in New Zealand there was an expert witness pathologizing those reacting to noise or exhibiting annoyance. Two questions emerge from this claim that annoyance is the result of mental illness. First, is there evidence supporting such a proposition, and second, if so what might the underlying annoyance mechanism be? It is true that individuals who have been diagnosed with certain types of

mental disorders react differently to noise. The WHO (2003) defines a mental disorder as:

“...the existence of a clinically recognizable set of symptoms or behaviour associated in most cases with distress and with interference with personal functions”

Working with this definition then there is certainly evidence in the health literature suggesting that people who have high levels of stress, anxiety, or depression are more likely to be annoyed when exposed to community noise than those who do not. Perhaps a conclusion we can draw from this is that people in the community recovering from mental health complaints, the introduction of community noise may negatively impact the recovery process. International clinical research indicates that one third of survivors with traumatic brain injury suffer debilitating symptoms of noise sensitivity (Dischinger, 2009). Given that there are approximately 24,000 brain injury cases in New Zealand every year, this would equate to 8,000 new noise sensitive individuals each year from traumatic brain injury alone. Noise sensitivity is also a common symptom associated with migraines and a number of psychological disorders, including schizophrenia, dyslexia, and autistic spectrum disorder. Thus we can conclude that the presence of a mental illness may influence noise annoyance.

Another interesting finding is that, in certain groups predisposed to mental illness, the introduction of community noise may lead to substantial mental health problems (EnHealth, 2004; Niemann & Maschke, 2004). Such a finding is consistent with how many mental illnesses are explained by clinical psychiatry. The diatheses-stress model proposes that psychiatric disturbances are caused by a genetic predisposition (i.e., diatheses) coupled with environmental stress. Thus if unwanted noise is classified as a stressor then community noise may lead to mental illness in some susceptible individuals. Dr Bridget Osborne (2007), a general practitioner from Wales, reports a significant increase in depression amongst local people following the erection of wind turbines in 2002.

Some acousticians have raised the possibility that those reacting to noise may suffer from somatoform disorder, a condition characterised by physical symptoms in the absence of any identifiable cause. Such a position is only defensible if one can argue that community noise does not constitute a stressor. Thus in this instance the acousticians, straying far beyond their expertise, are tendering propositions that cannot be supported by the peer-reviewed literature. A second phenomena advanced by acousticians revolves around the power of voodoo, or what is called the “nocebo effect”. From the outset the nocebo effect assumes that the presence of a stimulus is not harmful, and it is the belief of the individual that leads to compromised health. The research reported in the sections on noise sensitivity above and sleep below more than convincingly informs us that, in certain contexts and for substantial numbers of people, community noise can in fact lessen health. The subtext of the nocebo argument is that all research into the health effects of community noise, including turbine noise, should be halted and the existing reports suppressed or censured. Such a position, it can be argued, is not in the public good.

10. SLEEP DEPRIVATION AND HEALTH

Sleep

Sleep is a state of arousal characterized by an unresponsiveness to environmental stimuli and an absence of conscious activity. Every living organism contains, within its DNA, genes for a body clock which regulates an activity-inactivity cycle. In mammals, including humans, this is expressed as one or more sleep periods per 24 hours. Sleep was previously thought to be a period of withdrawal from the world designed to allow the body to recuperate and repair itself. However, modern research has shown that sleep is primarily by the brain and for the brain. The major purpose of sleep seems to be the proper laying down and storage of memories, hence the need for adequate sleep in children to facilitate learning and the poor memory and cognitive function in adults with impaired sleep from whatever cause. Thus sleep coincides with the body's restorative processes, allows us to conserve energy, and is required for maintenance of good health. Sleep disturbance and impairment of the ability to return to sleep is not trivial as almost all of us can testify. In the short term, the resulting deprivation of sleep results in daytime fatigue and sleepiness, poor concentration and memory function. Accident risks increase. In the longer term, sleep deprivation is linked to depression, weight gain, diabetes, high blood pressure and heart disease.

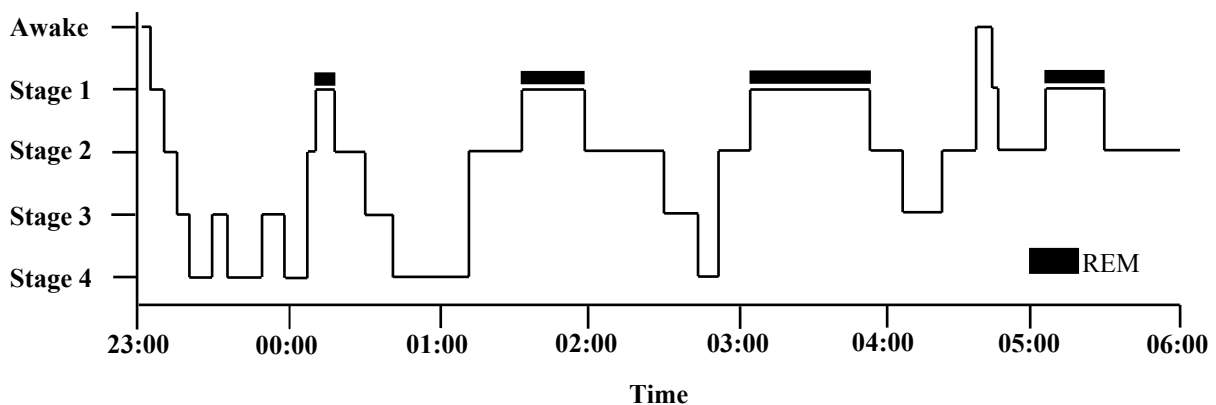


Figure X: A typical nights sleep for an adult. The duration of the sleep is seven hours. Note the cyclical pattern through the night, with the majority of non-REM sleep in the first third of the night and the majority of REM sleep in the last third of the night. Final waking is usually out of REM sleep

Humans have two types of sleep, slow wave (SWS) and rapid eye movement (REM). SWS is the deep sleep which occurs early in the night while REM or dreaming sleep occurs mostly in the second half of the night. Sleep is arranged in a succession of cycles, each lasting about 90 minutes. We commonly wake between cycles, particularly between the second and third, third and fourth and fourth and fifth cycles. Awakenings are not

remembered if they are less than 30 seconds in duration. As we age, awakenings become more likely and longer so we start to remember them.

Sleep and Noise

Noise interferes with sleep in several ways. First, it may be sufficiently loud or annoying to prevent the onset of sleep or the return to sleep following an awakening. It is clear also that some types of noise are more annoying than others. Constant noise is less annoying than irregular noise which varies in frequency and loudness, for example, snoring, particularly if accompanied by the snorts of sleep apnoea (breath holding). Second, noise experienced during sleep may arouse or awaken the sleeper. A sufficiently loud or prolonged noise will result in full awakening which may be long enough to recall. Short awakenings are not recalled as, during the transition from sleep to wakefulness, one of the last functions to recover is memory (strictly, the transfer of information from short term to long term memory). The reverse is true for the transition from wakefulness to sleep. Thus only awakenings of longer than 20-30 seconds are subsequently recalled. The Figure below (Figure 10), taken from Miller (1974), clearly shows that low level noise affects the second phase of SWS (i.e., stage II), the phase of sleep that we enter after having just ‘dozed off’. However, a warning must be sounded here. Miller (1974) and scores of others have used “reported awakenings from sleep” as an index of the effects of noise. Because most sleep disturbances are not recalled, this approach is not a valid measure of the effects of noise on sleep, and research that relies on recalled awakenings alone may therefore underestimate the effect.

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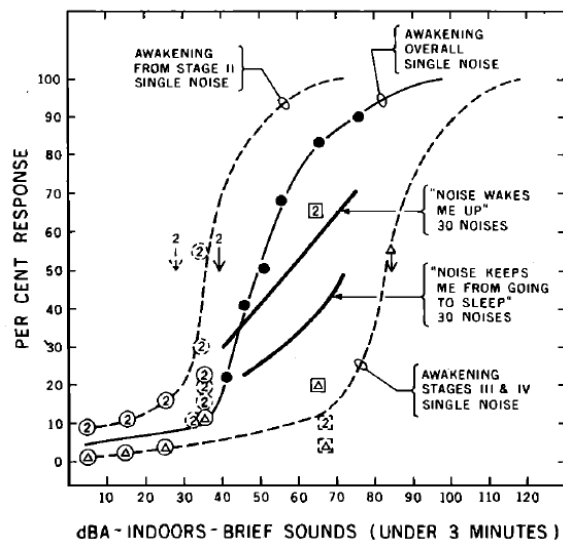


Figure 10 : Reported awakenings as a function of noise level plotted for different stages of sleep (from Miller, 1974).

Noise insufficient to cause awakening may cause an arousal. An arousal is brief, often only a few seconds long, with the sleeper moving from a deep level of sleep to a lighter level and back to a deeper level. Because full wakefulness is not reached, the sleeper has no memory of the event but the sleep has been disrupted just as effectively as if wakefulness had occurred. It is possible for several hundred arousals to occur each night without the sufferer being able to recall any of them. The sleep, because it is broken, is unrefreshing resulting in dozziness, fatigue, headaches and poor memory and concentration, many of the symptoms of “wind turbine syndrome” reported by Pierpont (2009).

Arousals are associated not just with an increase in brain activity but also with physiological changes, an increase in heart rate and blood pressure, which are thought to be responsible for the increase in cardiovascular risk. A clear relationship between high blood pressure and aircraft noise exposure has been demonstrated (Haralabidis, 2008) and between traffic noise and high blood pressure for adults (Barregard 2009) and, worryingly, for preschool children (Belojevic 2007). Arousals may be caused by sound events as low as 32 dB(A) and awakenings with events of 42 dB(A) (Muzet and Miedema 2005). Arousals in SWS may trigger a parasomnia (sleep walking, night terrors etc.). Pierpont (2009) notes that parasomnias developed in some of the children exposed to turbine noise in her study of wind turbine syndrome.

Arousals can be caused by aircraft, railway and traffic noise. In one study of aircraft noise, arousals were four times more likely to result than awakenings (Basner 2008a) and resulted in daytime sleepiness (Basner 2008b). Freight trains are more likely to cause arousals than passenger trains, presumably because they are slower, generating more low frequency noise and taking longer to pass (Saremi 2008). The noise of wind turbines has been likened to a “passing train that never passes” which may explain why wind turbine noise is prone to cause sleep disruption. A recent study of over 18,000 people has shown a link between exposure to traffic noise and “the risk of getting up tired and not rested in the morning (de Kluizenaar, 2009). This study, together with that of Basner (2008b) confirms that excessive noise disturbs sleep sufficiently to impair its restorative properties and adds credence to the anecdotal reports of those living near wind turbines.

Repeated night-time exposure to noise will result in the accumulation of cortisol in the blood stream. Long-term noise-induced elevation of cortisol during the sleep period can produce the symptoms of stress and depression (Harris et al, 2000), and a suppression of the immune system that can lead to disease. Sleep disturbance can also result in a reduction in waking vigilance, memory, learning, and concentration, and mood. Additionally, sleep disturbance can give rise to symptoms that mimic chronic fatigue syndrome. Fatigue can be physical (e.g., feelings of lethargy) or mental (e.g., feelings of somnolence). Chronic fatigue syndrome is characterised by a number of debilitating symptoms including ongoing muscular pain, poor digestion, impaired thought, and mental exhaustion. A structure in the brain known as the reticular activating formation, which mediates our general levels of arousal, has been implicated in fatigue. There are now scores of studies attesting to the fact that the ongoing disruption of sleep will result in mental and physical exhaustion, though we do not need a scientist to tell us this! The

WHO (Niemann & Maschke, 2004) report that approximately 25% of their sample ($n=8325$) reported noise-induced sleep disturbances, and furthermore, that those reporting sleep disturbances were at greater risk of suffering depression, hypertension, and migraines. Additionally, respondents in a Swedish study who reported being annoyed by wind turbine noise were statistically more likely to report feelings of tiredness and tension (Pedersen & Persson, 2007).

Belojevic, Jakoviljevic & Aleksic (1997) report that those residing in noisy areas have significantly more difficulties falling asleep, more night-time awakenings, worse subjective sleep quality and increased tiredness compared to those living in less noisy areas. However, as stated, sleep may be disturbed due to noise level or due to psychological responses to the noise. Often the probability of sleep disturbance is not a function of the absolute level of the noise source itself but rather the difference between the noise source and the ambient background sound levels. Furthermore, the patterns of the noise across time should also be taken into effect. For example, a dripping tap at night can cause substantial interruptions to sleep even though the noise itself is barely audible.

As children develop, both the distribution of sleep in a 24-hour period and total sleep requirements change. A newborn infant requires 14 to 18 hours of sleep a night, decreasing to 14 or 15 hrs by age one, 11 or 12hrs by age four, and about 10hrs by age ten. Sleep needs further decrease as adolescence progresses, stabilising at 7 or 8 hrs in adulthood. The elderly tend to lose their capacity for extended sleep. They may sleep fitfully at night, but doze during the day, returning to the multiphasic sleep patterns of childhood.

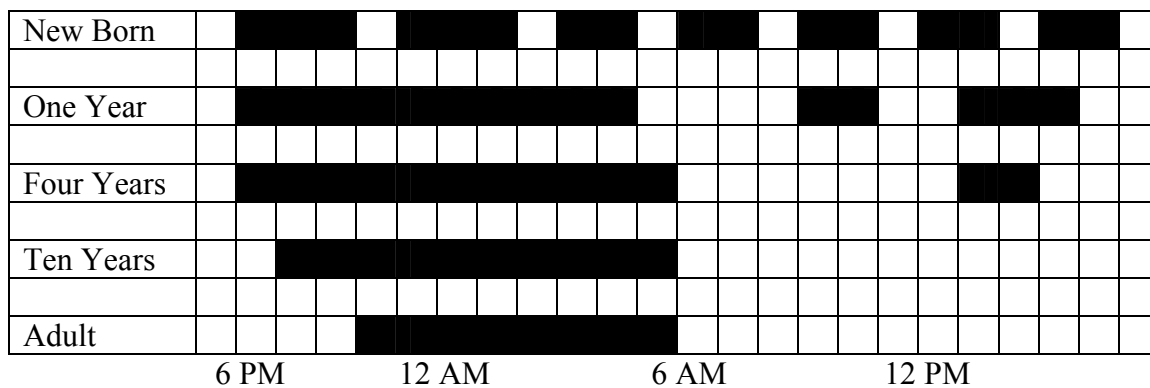


Figure X : Sleep requirements across the lifespan.

Finally, the elderly, shift workers, the physically or mentally ill, and children are more likely to suffer noise-induced sleep loss than others (Berglund et al., 1999; Niemann & Maschke, 2004). Children are especially sensitive to noise, and are at greater risk of disturbed sleep as annoyance to noise increases. The WHO reports that children who reported noise-induced sleep disturbances were more likely to be diagnosed with

migraine or depression (Niemann & Maschke, 2004). One study states (EnHealth, 2004):

“There is equivocal evidence that chronic noise exposure affects child mental health and sleep”.

One report on the health effects of wind turbines made the following statement in relation to sleep disturbance and children (Kamperman & James, 2008):

“There is no mention of the nighttime sound level recommendations set by the World Health Organization (WHO) in their documents on Community Noise or their “Report on the third meeting on night noise guidelines.” In those documents WHO recommends that sound levels during nighttime and late evening hours should be less than 30 dBA during sleeping periods to protect children's health. They noted that a child's autonomous nervous system is 10 to 15 dB more sensitive to noise than adults. Even for adults, health effects are first noted in some studies when the sound levels exceed 32 dBA Lmax. These levels are 10-20 dBA lower than the sound levels needed to cause awakening.”

The WHO Regional Office for Europe in collaboration with the European Union established a working party in 2003 to examine the effects of night time noise on sleep disturbance and health. Their brief was to review the current evidence and produce recommendations on permissible night time noise levels. The work concentrates on road traffic and aircraft noise as generating the most complaints and the subjects of most research. A preliminary report was published in 2007 (WHO, 2007), and the main finding of the working party can be viewed in Table 5. Unexpectedly, the WHO revised the 30 dB criterion up to 40 dB in its 2009 documentation, Night noise guidelines for Europe (WHO, 2009). The recommendation that a level of 40 dB should be the night noise guideline for Europe seems odd in the light of the conclusions of the effects of sound levels between 30 and 40 dB found in the literature. A value of 21 dB was used for sound attenuation from outside a building to inside, much greater than the 10-15 dB usually cited. Because New Zealand houses are often constructed from light timbers rather than brick or stone, and with respect to Figures 4 and 5 above, it can be easily argued that the original recommendation, 30 dB, should be adopted for turbine noise in the New Zealand context.

Table 5: Findings of the WHO noise working (2007) party

“The review of available evidence leads to the following conclusions.

- Sleep is a biological necessity, and disturbed sleep is associated with a number of adverse impacts on health.*
- There is sufficient evidence for biological effects of noise during sleep: increase in heart rate, arousals, sleep stage changes, hormone level changes and awakening.*

- *There is sufficient evidence that night noise exposure causes self-reported sleep disturbance, increase in medicine use, increase in body movements and (environmental) insomnia.*
- *While noise-induced sleep disturbance is viewed as a health problem in itself (environmental insomnia) it also leads to further consequences for health and well-being.*
- *There is limited evidence that disturbed sleep causes fatigue, accidents and reduced performance.*
- *There is limited evidence that noise at night causes clinical conditions such as cardiovascular illness, depression and other mental illness. It should be stressed that a plausible biological model is available with sufficient evidence for the elements of the causal chain.”*

“For the primary prevention of subclinical adverse health effects in the population related to night noise, it is recommended that the population should not be exposed to night noise levels greater than 30 dB of $L_{\text{night, outside}}$ during the night when most people are in bed. Therefore, $L_{\text{night, outside}}$ 30 dB is the ultimate target of Night Noise Guideline (NNGL) to protect the public, including the most vulnerable groups such as children, the chronically ill and the elderly, from the adverse health effects of night noise.”

Sleep and Wind Turbine Noise

Wind turbine noise has the potential to cause arousals, sleep fragmentation and sleep deprivation. It is unfortunate that the noise from wind turbines are often at their loudest and most disturbing at night due to an increase in atmospheric stability (Harry, 2007). Studies to determine if nocturnal wind turbine activity can induce increases in cortisol level are needed as no such research has yet been undertaken, though one study on the effects of wind turbine noise noted that respondents who were fairly or very annoyed by turbine noise had statistically higher mean stress scores than those who were not (Pedersen & Wayne, 2008). A British resident living in the proximity of a wind turbine writes (Harry, 2007):

“Our quality of life we had before the wind farm came has gone. We no longer control the way we live our lives, when we can work or sit in the garden, or at times even where we can sit in our own homes or get a full night’s sleep.”

In other research directly related to wind turbines one study reported that sixteen percent of respondents experiencing 35 dB(A) or more of noise suffered sleep disturbances due to turbine noise, with all but two respondents sleeping with an open window in summer

(Pedersen & Persson Waye, 2004). Others also report that wind turbines cause sleep deprivation (Davis, 2007; Harry, 2007). Residents in the vicinity of existing wind farms in the Manawatu region have reported hearing the turbines in their bedrooms at night, especially in summer even when windows are closed. Research indicates that sleep can be severely disturbed by noise, irrespective of its level, and thus the control and reduction of nocturnal noise must be given priority in the community. Reports from residents living near wind turbines in regards to sleep deprivation can be found in the literature. A recent study (Pedersen & Persson Waye, 2007) looking at the effects of wind turbine noise on sleep showed that 36% of respondents who were annoyed at wind turbine noise also reported that they suffered disturbed sleep (compare 9% for those not annoyed). The effect of wind turbines on sleep have yet to be quantified, though it appears that chronic sleep disturbance is the most common complaint of those living near wind turbines. Here are some comments reported in a British study (Harry, 2007):

“My symptoms are due to lack of sleep when the wind is from the east or northeast”

“Noise disturbances at night – when wind in a certain direction, interferes with sleep patterns, causing restlessness”

“It’s an irritating and tiring noise, especially when you have not had any sleep because of it”

Surveys of residents living in the vicinity of WTIs show high levels of disturbance to sleep. A 2005 survey of 200 residents living within 1km of a 6 turbine, 9MW installation in France showed that 27% found the noise disturbing at night (Butre 2005). A similar US survey in 2001 (Kabes 2001) of a “wind farm” in Kewaunee County, Wisconsin reported that 52% of those living within 400-800 metres found the noise to be a problem, 32% of those living within 800-1600 metres and 4% of those within 1600 and 3200 metres. Thus, the provision of evidence supporting noise-induced sleep disturbances from wind turbines has come from both case studies and quantitative research.

Bakker, (2009) report their observations on noise problems, including sleep deprivation, associated with wind turbines at least 3km from the affected properties. The Tararua, turbines are sited on a ridge and the affected properties are to the east in a river valley. Noise problems persisted despite the installation of sound reducing glazing. Nocturnal seismic noise monitoring showed noise bursts lasting at least 10 seconds, associated with an easterly wind, which the authors were confident originated from the turbines. The residents confirmed that the noise recorded was identical with that which disturbed their sleep. The authors speculate that the noise was transmitted through the ground. The importance of this report is not the mechanism for sound transmission but scientific confirmation that wind turbines can disturb sleep at distances of 3km. Previous anecdotal reports have often been dismissed as fanciful with assertions that sound transmission over such distances is impossible. While this seems, so far, to be an isolated case, it adds further evidence that much greater setbacks than those currently required are necessary to obviate sleep disturbance.

Studies of different alarm signals have shown that arousals and awakenings occur at lower sound levels with low frequency sounds than those of higher frequency (Bruck 2009). Repeated short beeps of 400-520 Hz were most intrusive, leading to arousal and awakening. Some argue that wind turbine noise has a considerable low frequency component and an impulsive nature which may, in part, explain its adverse effect on sleep. These effects have not gone unreported (Harry, 2007):

“I get little sleep when the noise from the turbines is constant in its low frequency noise. I feel so depressed, I want to get away and stay away until I know the wind direction has changed”.

11. A SUMMARY OF RESEARCH UNDERTAKEN ON WIND TURBINE NOISE

Preamble

Wind turbines are a new source of community noise, and as such their effects on public health are only beginning to emerge in the literature. The recognition of a new disease, disorder, or threat to health usually follows a set path. First, doctors and practitioners attempt to fit symptoms into predefined diagnostic categories or to classify the complaints as psychosomatic. Second, as evidence accumulates case studies begin to appear in the literature, and exploratory research is undertaken to obtain better descriptions of the symptoms/complaints. Third, intensive research is undertaken examining the distribution and prevalence of those reporting symptoms, the factors correlating with the distribution and prevalence of those symptoms, and ultimately to cause-and-effect explanations of why those reporting symptoms may be doing so.

In my reading of the literature the health effects of wind turbines are only beginning to be understood, and the research process is caught somewhere between these first and second stages. Note that case studies (e.g., Harry, 2007; Pierpont, 2009) and correlational studies (e.g., Pedersen, 2007; van den berg, 2008) are now starting to emerge in relation to the health effects and wind turbine noise, and so the possibility of detrimental health effects due to wind turbine noise must be taken with utmost seriousness. Indeed, the latest comprehensive study (van den berg, 2008) into the effects of turbine noise concludes:

“Annoyance with wind turbine noise was associated with psychological distress, stress, difficulties to fall asleep, and sleep interruption”

Certainly, there is not a single credible paper in the peer-reviewed literature stating that wind turbine noise is harmless to health. Contra to the assertion that wind turbines have no health related effects, there is an emerging body of evidence informing us that under certain circumstance wind turbines can have substantial physiological and psychological impacts on the community. A brief description of this evidence is now listed, and where possible, technical jargon has been omitted or minimised. It should be noted that, without exception, all of these studies have shortcomings, and indeed, research of this type is vulnerable to inherent limitations that serve to dampen its impact. However, the studies selected represent credible researchers undertaking difficult research, and their findings

should be reflected back to the previous sections of this monologue in order to gauge their full impact.

Harry (2007)

Dr Amanda Harry, a British General Practitioner, conducted surveys of 42 residents living near several different turbine sites and reported a similar constellation of symptoms from all sites. Of the 42 respondents, 81% felt their health had been affected, in 76% it was sufficiently severe to consult a doctor and 73% felt their quality of life had been adversely impacted. This study is open to criticism for a design that invited symptom reporting and was not controlled. While the proportion of those affected may be questioned it nevertheless indicates strongly that some members of the public are severely affected by wind turbine noise at distances thought by governments and industry to be safe.

Pederson et al., (2003, 2004, 2007 and 2008)

Pedersen and co-investigators have undertaken a series of investigations examining the relationship between turbine noise and health. In a 2004 paper ($n=351$) Pedersen reports the importance of individual and contextual factors alongside noise parameters, and the danger in generalising findings from other sources of community noise (e.g., road, rail, aircraft) to the wind turbine context (see Figure 4 above). In a 2007 paper ($n=754$), Pederson further explores these individual and contextual influences. They noted that those living in rural areas are more likely to be annoyed than those from suburban areas, and that those living in complex terrain (e.g., hills or rocky terrain) were more likely to be annoyed than those living on flat ground. The study found a strong association between annoyance and both lowered sleep quality and negative emotions. A paper published in 2008 ($n=1822$) reanalysed pre-existing turbine noise and annoyance data and concluded that turbine noise can impede health, especially for susceptible individuals. The paper also discussed the dangers of using noise level as a sole predictor of annoyance, and the strength of noise sensitivity indices in predicting annoyance.

Pedersen and others (2009) reported that annoyance increased with increasing sound levels, both indoors and outdoors (see Table 6). The proportions who were rather and very annoyed at different sound levels are shown in Table I. In summary, when outside, 18% were rather or very annoyed at sound levels of 35-40 and 40-45 dB(A) compared to 7% at 30-35 dB(A) and 2% at <30 dB(A). When inside, the equivalent figures were 1% at <30 dB(A), 4% at 30-35 dB(A), 8% at 35-40 dB(A) and 18% at 40-45 dB(A). Those respondents who had an economic interest in the turbines had lower levels of annoyance while negative views of the visual impact of turbines increased the likelihood of annoyance.

Although the authors do not seek to recommend minimum sound levels, they do note that turbine noise was more annoying than other sources, with the possible exception of railway shunting yards and was more noticeable at night. Reported associations between annoyance and symptoms of stress (headache, tiredness, tension and irritability)

confirmed that “annoyance” is more than irritation and is a marker of impaired health. They conclude that (Pedersen et al, 2009):

“...nighttime conditions should be treated as crucial in recommendations for wind turbine noise limits.”

Nevertheless, it is clear from this analysis that external predicted turbine sound levels should be less than 35 dB(A), considerably less than those permitted by European noise standards, in order to reduce effects on nearby residents to acceptable levels.

Table 6: Percent responding to level of annoyance towards outdoor and indoor wind turbine noise levels for five categories of level in 5-dB(A) sound level intervals. Parentheses present 95% confidence intervals. (From Pedersen 2009a)

	Predicted <i>A</i> -weighted sound pressure levels dB(A)				
	<30	30–35	35–40	40–45	>45
Outdoors	<i>n</i> =178	<i>n</i> =213	<i>n</i> =159	<i>n</i> =93	<i>n</i> =65
Do not notice	75 (68–81)	46(40–53)	21(16–28)	13 (8–21)	8(3–17)
Notice, but not annoyed	20 (15–27)	36(30–43)	41(34–49)	46 (36–56)	58(46–70)
Slightly annoyed	2 (1–6)	10(7–15)	20 (15–27)	23 (15–32)	22(13–33)
Rather annoyed	1 (0–4)	6(4–10)	12 (8–18)	6 (3–13)	6(2–15)
Very annoyed	1 (0–4)	1(0–4)	6 (3–10)	12 (7–20)	6(2–15)
Indoors	<i>n</i> =178	<i>n</i> =203	<i>n</i> =159	<i>n</i> =94	<i>n</i> =65
Do not notice	87 (81–91)	73(67–79)	61(53–68)	37 (28–47)	46(35–58)
Notice, but not annoyed	11(7–17)	15(11–20)	22 (16–29)	31(22–31)	38(28–51)
Slightly annoyed	1 (0–4)	8(5–12)	9 (6–15)	16 (10–25)	9(4–19)
Rather annoyed	0 (0–2)	3(1–6)	4 (2–8)	6 (3–13)	5(2–13)
Very annoyed	1 (0–4)	1(0–4)	4 (2–8)	10 (5–17)	2(0–8)

Pedersen, Hallberg, and Wayne (2007)

Pedersen conducted in-depth interviews with 15 people living within close vicinity of wind turbines. A qualitative method known as grounded theory was selected to inform both data collection and data analysis. Respondents opinions of the turbines and the turbine noise was largely determined by their personal values about the living environment. The feeling of intrusion was associated with feeling a lack of control, subjected to injustice, a lack of influence, and not being believed. Various coping strategies were engaged, such as rebuilding their houses or complaining. Most however displayed learned helplessness and simply tried to ignore wind turbine noise.

van Der Berg (2008)

van den Berg and colleagues (2008) from the University of Groningen in the Netherlands have recently published a major questionnaire study of residents living within 2.5km from wind turbines. A random selection of 1948 residents were sent a similar questionnaire to that used by Pedersen in her studies in Sweden (2003, 2004, 2007 and 2008), questions on health, based on the validated General Health Questionnaire (GHQ), were added. 725 (37%) replied which is good for a survey of this type but, nevertheless may be a weakness. Non-respondents were asked to complete a shortened questionnaire. Their responses did not differ from full respondents suggesting the latter are representative of the population as a whole.

Questions on wind turbine noise were interspersed with questions on other environmental factors to avoid bias. The sound level at the residents' dwellings was calculated, knowing the turbine type and distance, according to the international ISO standard for sound propagation, the almost identical Dutch legal model and a simple (non spectral) calculation model. The indicative sound level used was the sound level when the wind turbines operate at 8 m/s in daytime, that is, at high, but not maximum power. Noise exposure ranged between 24 and 54 dB(A). It is worth noting that the industry was approached for assistance in the research but refused. Complaints such as annoyance, waking from sleep, difficulty in returning to sleep and other health complaints were related to the calculated noise levels.

The research team concluded that *"Sound was the most annoying aspect of wind turbines"* and was more of an annoyance at night. Interrupted sleep and difficulty in returning to sleep increased with calculated noise level as did annoyance, both indoors and outdoors. Even at the lowest noise levels, 20% of respondents reported disturbed sleep at least one night per month. At a calculated noise level of 30-35 dB(A), 10% were rather or very annoyed at wind turbine sound, 20% at 35-40 dB(A) and 25% at 40-43 dB(A). van den Berg concluded also that, contrary to industry belief, road noise does not adequately mask turbine noise and reduce annoyance and disturbance. Bolin (2009) has shown that vegetation noise does not mask turbine noise as well as expected. With regard to health it was concluded that:

"There is no indication that the sound from wind turbines had an effect on respondents' health, except for the interruption of sleep. At high levels of wind turbine sound (more than 45 dB(A)) interruption of sleep was more likely than at low levels. Higher levels of background sound from road traffic also increased the odds for interrupted sleep. Annoyance from wind turbine sound was related to difficulties with falling asleep and to higher stress scores. From this study it cannot be concluded whether these health effects are caused by annoyance or vice versa or whether both are related to another factor."

Though the conclusion itself appears to contradict itself, and the assertion that only sleep is a factor cannot be concluded from their data as they did in fact find a relationship between annoyance and stress, but they could not conclude which one caused the other.

Thorne (2009)

As part of his research into the perception of low amplitude intrusive sound Thorne has found that there are significant differences in response between people living in rural areas near wind farms and people living in urban communities. Based on a series of sound simulations he found that the rural people interviewed found the sound of the turbines ‘unpleasant, annoying and disturbing’ whereas the urban community, who had not seen the wind farms or turbines, found the sounds ‘pleasant and gentle’. A series of noise sensitivity questionnaires also indicated a statistically significant difference between the two communities with the rural community more sensitive. Further research at two different locales near wind farms show that individuals initially accepting of wind farms can become increasingly sensitised to very low levels (outdoor LAeq 30 dB or less) of sound from wind farms due to the visual dominance of the turbines themselves and to noise that causes sleep disturbance or perceived adverse health effects. Sleep disturbance is caused by the varying nature of the wind farm noise; the ‘rumble-thump’ or ‘swishing’ sound heard inside the home at levels of LAeq 15 to 20 dB or less and cannot be avoided. The work of Thorne (2009) was to establish a practical methodology to integrate human perception of sound, personal sensitivity and relevant sound character analysis.

Jabben (2009)

Jabben and colleagues (2009) from RIVM, the Dutch National Institute for Public Health and Environment, were commissioned by the Dutch Government to examine the impact of different values of loudness on the ability to meet targets for onshore wind power generation. They reviewed current evidence and noted that, at present, 440,000 inhabitants (2.5% of the population) were “*receiving significant noise contribution from wind turbine noise of which 1,500 are expected to suffer severe annoyance. It is remarkable that almost half of this number already occurs within the range Lden 30-40db(A)*”.

Pierpont (2009)

Pierpont (2009) has recently completed a very detailed case-series study of ten families around the world who have been so affected by wind turbine noise that they have had to leave their homes, nine of them permanently. The turbines ranged from 1.5 to 3MW capacity at distances between 305 to 1500m. The group comprised 21 adults, 7 teenagers and 10 children of whom 23 were interviewed. While this is a highly selected group, the ability to examine symptoms before, during and after exposure to turbine noise gives it a strength rarely found in similar case-series studies. The subjects described the symptoms of wind turbine syndrome outlined above and confirmed that they were not present before the turbines started operation and resolved once exposure ceased. There was a clear relationship between the symptoms, even in children, and the noise exposure. Pierpont reports also that all (actually 14 of 21) adult subjects reported “*feeling jittery inside*” or “*internal quivering*”, often accompanied by anxiety, fearfulness, sleep disturbance and irritability. Pierpont hypothesises that these symptoms are related to low frequency sound and suggests physiological mechanisms to explain the link between turbine exposure and the symptoms.

Of particular concern were the observed effects on children, include toddlers and school and college aged children. Changes in sleep pattern, behaviour and academic performance were noted. Seven of the ten children had a decline in their school performance while exposed to wind turbine noise which recovered after exposure ceased. In total, 20 of 34 study subjects reported problems with concentration or memory.

Pierpont's study mostly addresses the mechanism for the health problems associated with exposure to wind turbine noise rather than the likelihood of an individual developing symptoms. Nevertheless, it convincingly shows that wind turbine noise is strongly associated with the symptoms she describes, including sleep disturbance. She concludes by calling for further research, particularly in children, and a two-kilometre setback distance. A recent paper (Todd et al, 2008) has shown that the vestibular system in the human ear, the part concerned with detection of movement and balance, is exquisitely sensitive to vibration at frequencies of around 100Hz. Pierpont claims that these findings support her hypotheses.

Nissenbaum (2010)

Nissenbaum (2010) has presented the preliminary results of a study of residents living downwind and within 300-1100m (mean 800m) of a wind farm at Mars Hill, Maine, USA. The 28 1.5MW turbines are sited on a 200m high ridge overlooking the homes. Thus far 22 of about 35 adult residents have been interviewed and compared with a randomly selected control group living approximately six kilometres away. Of the 22, 18 report new or worsened sleep onset disturbance at least twice a week, for 9 at least 5 times per week (controls 1/28). A further eight of the 22 report new or worsened headaches (controls 1/28) and 18/22 reported new or worsened mental health symptoms (stress 12/22; anger 18/22; anxiety 8/22; hopelessness 12/22; depression 10/22; controls 0/28).

The 22 subjects received 15 new or increased prescriptions from their physicians in the 18 months between the start of turbine operation and the study, the majority for psychoactive medication (control group: 4 prescriptions, none for psychoactive medication). All but one of the 22 participants have reported reduced quality of life and 20 are consider moving away (controls: 0/28 for both). The study may be criticised for it's relatively small numbers of subjects but the presence of a control group, well matched for age and gender, adds considerable power. All differences between the groups are statistically highly significant. The turbine noise levels at this site may be enhanced by the high concentration of turbines and the geography but the severe sleep disturbance, psychiatric symptomatology and increased medication requirement in the study group confirms the potential of wind turbine noise to adversely affect health at distances claimed to be safe.

12. NOISE STANDARDS AS GUARDIANS OF PUBLIC HEALTH

Standards

Standards have been an unqualified success in the field of engineering, science, and commerce. The ability to stipulate a standardised procedure, test, definition, or specification is akin to creating a common language or frame of reference that facilitates communication and understanding between diverse groups.

However, the existence of a standard does not presuppose that the standard itself is the correct procedure, test, definition, or specification. Nor does it imply that the standard is actually useful or effective. That is undoubtedly the intention, but the reality is that standards are evolving entities that are constantly undergoing review and change. This is evident in relation to noise standards internationally and domestically, some examples being:

(a) The WHO⁵ statements that:

“It is evident that noise emission standards have proven insufficient and that the trends in noise pollution are unsustainable”.

“Continuing efforts will be made to improve its [the Guidelines for Community Noise] content and structure”.

(b) Calls from acoustics experts to update current American noise standards⁴⁸:

“Changes in present USA noise-measurement procedures and noise-control guidelines are proposed that provide more accurate predictions of annoyance, related adverse effects, and criteria for setting tolerable limits of noise exposure in residential areas”

(c) The Department of Health and Aging in Australia⁹ calls for an immediate review of all noise guidelines, standards and policies in light of the adverse health outcomes being associated with community noise.

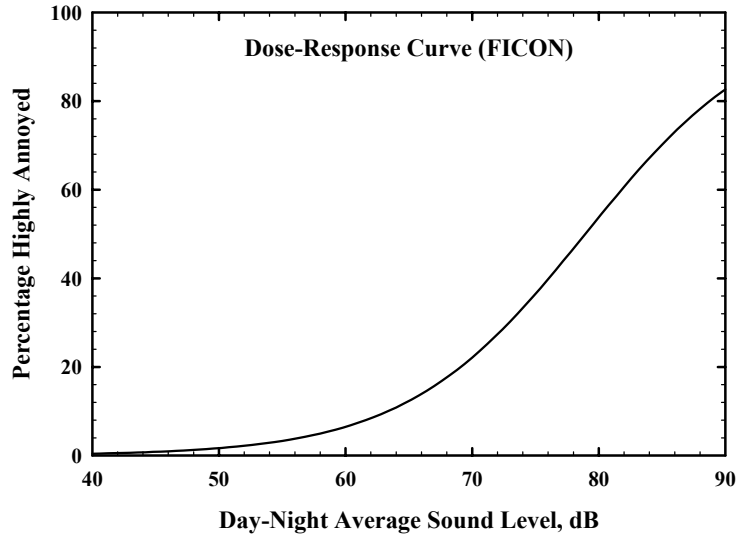
That standards are not necessarily definitive is further demonstrated by the lack of agreement that can exist amongst experts in relation to standards. For example, the classification of noise into broad ranges of frequency (e.g., low, medium, and high frequency) lacks universal agreement. and there are different definitions in Germany (DIN 45680:1997), The United States of America (ANSI S12.9), Sweden (SOSFS 1996L17), and both Denmark and Holland.

Additionally, standards perpetually lag behind research. In England wind turbine noise is predicted and assessed using standards that were developed for substantially smaller wind turbines⁶.

The dose-response curve: The bedrock of standards

Noise standards, even those advocated by the WHO in the past, are based on the dose-response curve (*aka* the Schulz curve)³⁰. The dose-response curve, constructed from dose response data, plots noise annoyance as a function of noise level. Users of a dose-

response curve define a level of annoyance that they are willing to accept and then, either graphically or numerically, determines the level of noise that yields the predefined annoyance level. The following figure illustrates an actual dose-response curve:



Below is the same curve but with a shortened x-axis (now from 57 to 68 dB) accompanied by actual measurements of noise annoyance for aircraft noise. Note the incompatibility of the theoretical curve and the empirically derived data (Figure taken from Fidell, 2003⁴⁹).

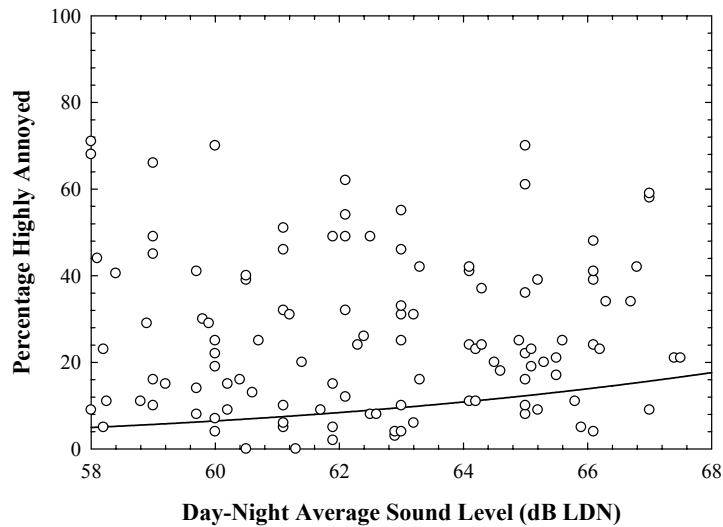


Figure 2: Percentage annoyed at aircraft noise plotted as a function of noise level (dB LND). The solid curve is from the

As the two figures show, annoyance reactions to noise vary substantially and do not appear to be correlated with noise level. Other factors associated with annoyance have been identified, both personal and social, and need to be accounted for when attempting to predict noise annoyance⁹. It can be concluded that the high variability between individuals and groups makes it difficult to model the relationship between noise and annoyance. Yet plots such as the two above are still used to determine noise standards.

In fact, the level of noise (that is, how loud the noise is) only explains 10 – 25% of an individual's response to noise⁹:

“Noise exposure alone accounts for only part of the variance on individuals' response to noise, whether annoyance or dissatisfaction, sleep disturbance, or effects on hearing and task performance. Individual reactions depend on the characteristics of the noise, the noise source, and the individual's attitude to the noise and the noise source.”

Schomer and Associates (2001)³⁰, commenting on the validity of dose-response curves, noted that (bold scripts are mine):

*“One hallmark of this figure, and many like it, is the large amount of scatter to the data. One may question the usefulness of figures like Figure 5 (a **dose-response curve**) in view of the large amount of scatter to the data. There is just too much scatter.”*

The WHO⁵, commenting on the dangers of averaging individual annoyance data, state:

“The correlation between noise exposure and general annoyance is much higher at the group level than the individual level”

and others²⁶:

“Such nonacoustic variables are repeatedly estimated to account for more variance in annoyance scores in survey data than do acoustical variables.”

The dose-response curve has been heavily criticized in the acoustical literature, and indeed attracted severe criticism upon its unveiling some 25 years ago on the basis that it failed to account for nonacoustic factors⁴⁹:

“the accuracy and precision of estimates of the prevalence of a consequential degree of noise-induced annoyance yielded by functions of noise exposure leave much to be desired”

A further criticism of using dose-response curves is that the users often extrapolate below levels of 40 dB(A)³⁰. This is not good practise and involves making a large number of assumptions that the data can not support²⁸. Other studies construct dose-response curves using received noise complaints as a measure of annoyance. Such curves will severely

underestimate the levels of annoyance as only a small number of people affected are likely to complain, as has been reported in the literature^{9,30,49}.

What is being set is an “annoyance threshold”, expressed in physical levels of the stimulus. The question is, at what level of noise does one estimate the threshold? The level of noise at which ten percent of people are annoyed? Why not 5% or why not 15%? These values are not being informed by health research, so what are they being informed by?

In Australia the criterion for aircraft noise was set at a point in which no more than 10 per cent of the population would be *severely* affected. Such criteria setting reflects a utilitarian approach to public health that is simply not sanctioned by modern society. Would we put an additive in a city’s water supply that would benefit 90% of citizens and make the other ten percent ill?

Standards that employ thresholds do not account for individual differences and possess a “one size fits all” approach. Large individual differences exist in the response to noise, one can not simply select a noise level (e.g., 30 dB(A)) and state, for example, that 10% of people are going to be annoyed by noise. The reality is that there will be, at that noise level, some individuals that will be severely affected by the noise and some who will not at all be affected at all.

Current international standards for acceptable levels of community noise are based on the dose-response curve. This approach to establishing acceptable noise levels lacks validity and has been rightly lambasted by acousticians and health researchers alike^{30,49}.

Whilst standards afford excellent validity in the specification of physical entities such as length, speed, or electromotive force, they struggle when applied to predicting human responses, at least when constructs such as dose-response curves are used.

NZS6808:1998

Currently NZS6808 has little to do with health. We are looking at the relationship between a physical measure and a psychological/physiological response. Where then is the comprehensive treatment of health risks to the degree that is evident for physical measurement? I believe it is absent. In its place is a noise level threshold, derived from a dose response curve, as a ‘proxy’ for an appropriate human health measurement.

For its veracity NZS6808 relies upon its relationship to international standards and guidelines (*argumentum ad verecundiam* or “appeal to authority”) when, as I have shown, many of the international standards are themselves based on erroneous measures (e.g., dose-response curves).

NZS6808 is currently under review, which in addition to the concerns I have outlined above, seems particularly necessary, given the substantial increase in size and power output of turbines since the standard was formulated in 1998.

I believe that standards built upon dose-response curves are not suitable yardsticks for determining the measurement, control, or prediction of psychological responses and health sequels, and are therefore not appropriate for the measurement, control, or prediction of psychological responses to wind turbine noise.

In support of that I observe that the predictions of dose-response curves and prevalence of wind turbine noise are regularly discordant³.

Personal correspondence from Eja Pedersen, a well respected researcher on the psychological and health impacts of wind turbine noise, argues that the relationship between noise level and annoyance is not the relationship of interest. In relation to an unpublished study (**note:** this research has since been published⁶⁶) she had this to say:

“I can already now say that the results are similar to those of the Swedish study, i.e. there is no direct association between sound levels and impaired health, but between sound levels and noise annoyance, and between noise annoyance and impaired health.”

In a recent WHO report¹² (WHO: 2004) on noise and health the primary variable used to assess the effects of noise on health was noise annoyance, and not noise level. The report found that a substantial number of health problems were associated with noise annoyance levels. Furthermore, by controlling a number of variables statistically, the report concluded that there was strong and compelling evidence of a cause-and-effect relationship between noise annoyance and adverse health.

The reality is that so long as a noise is audible then it has the potential to be annoying (e.g., a dripping tap), and furthermore, that in being annoying, an audible noise has the potential to compromise health and well-being. As reported by the WHO⁵:

“According to Rehm (1983) individual responses to noise may be more highly correlated with symptoms of ill-health than with the noise itself”.

Thus there are, in my opinion, two criteria that are important when judging if noise could be potentially detrimental to health due to annoyance. First, if the noise is audible. Second, the context in which the noise is occurring and the sociopsychological factors associated with the individuals responding to that audible noise.

In modern times noise annoyance is seen as a product of the interaction between the physical properties of the sound and psychological attributes of the listener⁵⁰:

“In noise research the concept of a simple stimulus-reaction-relationship very soon proved to be inadequate; moreover, the international field studies showed that the effect of sound is moderated by various social, biological, and psychological conditions.”

The literature indicates that it is not the level *per se* of the incoming noise that has the greater impact on human response, but rather its meaning. For example, the soft sobbing of a loved one will elicit a far greater response than, for example, the sound of heavy rain. A dripping tap in the dead of night constitutes a further example, as does finger nails down a blackboard or the quiet background buzz of a mosquito. Thus, it is not the overall level of the sound that is important; it is the significance that we attach to the sounds that is of importance^{9,51,52}

Best practise should prevail, not a reliance on standards or guidelines. Commenting on their own guidelines, the WHO⁵ state:

“Supplementary to the guidelines values given..., precautions should be taken for vulnerable groups and for noise of certain character (e.g. low-frequency components, low background noise).”

and⁵:

“Risk groups do not consist of just the group with impaired hearing (10% of the population) but in reality a much larger group. The noise load for these persons

may be assumed to be more serious than shown by the traditional dose-response relationships”

and more importantly:

“For every noise protection guideline the issue of vulnerable subgroups of the population has to be considered”

Non-standards based approaches to turbine placement

The WHO⁵ state:

“Almost all noise effects are undesirable, yet in many cases it is not definite whether these effects must be judged as harmful and thus as acceptable or not. Ultimately this is a normative and societal decision”

and further:

“The actual “critical limits” cannot be found by research. Standards are set by society as the outcome of a normative effort, rather than emerging from an objective “scientific” result”.

If not standards then what? The literature contains a number of excellent papers detailing how noise levels should be set within a community without recourse to standards. I give the following references that clearly outline how such procedures should be conducted^{55,56,57,58}.

Maris et al.,⁵⁷ start from the premise that noise exposure is a social experience. They note the limitations of dose-response approaches, and present a series of experiments demonstrating that if individuals are disenfranchised from the decision-making processes effecting their communities then they are more likely to become annoyed by the noise. On the basis of their data they concluded that perceived procedural fairness was a major determinant of noise reactions. Thus⁵⁷:

“Instead of marginalizing deflections from the dose-response curve as ‘response bias’, such deflections need to be recognised as a key to a better understanding of the psychology of noise annoyance”

They recommend that social psychological theories of justice be applied, and indicated a number of candidate procedural fairness criteria that could be used. They conclude⁵⁷

“There will be cultural differences with regard to which type of procedure people regard as just, but the wish to be treated justly seems to be universal... Unsound management is best avoid.”

Noise is a social problem, and yet research addressing noise effects rarely factors in a social perspective. In a follow up study, Maris et al.,²⁶ detail a form of potential social involvement in the decision of where to site noise generators. They state²⁶:

“If future noise annoyance levels are to be kept to a minimum, it is needed that, in addition to the important and impressive developments that are being made in the field of noise reduction engineering, both noise researchers and policy makers address social nonacoustical codeterminants of noise annoyance.”

As it stands, there appears to be no social or cultural determinants of noise annoyance in NZS6808.

In a paper entitled “Community perspectives of wind energy in Australia: the application of a justice and community fairness framework to increase social acceptance” Gross⁵⁵ comments on the effects of outcomes that benefit some sections of the community at the perceived expense of others. She states⁵⁵:

“Divisions in local communities frequently happen where there are conflicting perspectives of values and rights and conflicting interests for land use and natural resource management. A case in point is wind energy projects where community divisions have been particularly pronounced”

Studying a small rural community in Australia that had been divided over a wind turbine complex proposal, Gross claims that the cause of the conflict was a perceived lack of fairness. A framework of community fairness was then developed to enhance both procedural and distributive justice. Her research demonstrated that⁵⁵:

“...the procedural justice principles of appropriate participation, the ability of a voice to be heard, adequate information, being treated with respect, and unbiased decision-making were considered important by interviewees”

The following table from Gross contains suggestions as to how social acceptance can be facilitated (note: EIS = environment impact statement):

Table 1
Interviewee suggestions to confer greater legitimacy on outcome

Category	Suggestion
Consultation process	<ul style="list-style-type: none"> ● Start process earlier to engage the community and avoid secrecy and suspicion ● Conduct consultation openly
Information	<ul style="list-style-type: none"> ● Copies of EIS should be made more available ● Impartial scientifically-based factual information required, not only on wind farm issues but also on renewable energy ● EIS should be independent from proponent and developed by an independent firm
Voice	<ul style="list-style-type: none"> ● Conduct meetings so that all participants have the opportunity to speak and be heard; restrict attendees to local community residents
Issues	<ul style="list-style-type: none"> ● Every issue should be responded to with a cogent argument as to why the issue will not have an impact on the community

Recommendations

1) If an acoustician does not have a postgraduate degree in a health related field, they should not be invited to give evidence on health matters. Likewise, if a health expert does not have an engineering-related degree they should not be invited to give evidence on the measurement of sound.

Community noise has the potential to degrade health. However, nobody is saying that airports should be closed, social gatherings restricted, or that motor vehicles be replaced with bicycles. What we must be conscious of, however, is that some individuals would do well to avoid living in areas in the proximity of known noise generators. Consequently, care needs to be taken in the construction of industrial complexes or public amenities within the vicinity of the public, with consideration given to abatement strategies or consent refusal being made on a case-by-case basis.

As with other noise sources there is individual variation in regards to the effects of wind turbine noise. It should be emphasised however that any argument stating that because only some suffer symptoms while others do not then those who claim to be suffering the symptoms must be making them up is a fallacy. In the field of epidemiology the differential susceptibility of individuals are known as risk factors. In terms of wind turbine noise these risk factors are still under study.

The aims of the RMA are to provide a healthy, sustainable environment and a full range of outdoor opportunities that people can use and enjoy in the work and leisure.

I recommend that noise level is not used as the sole metric with which to judge the potential health effects of wind turbine noise.

As it currently stands, the use of standards, formulated locally or otherwise, are inappropriate indices of the public health effects of wind turbine noise on individuals and communities. I recommend that NZS6808:1998 not be used as a standard with which to judge the psychological and health impacts of wind turbines.

It should be acknowledged that research always lags behind social experience. For example⁷³:

“A plausible explanation of the observed association is that wind turbine sound leads to annoyance for some people; annoyance that in turn possibly hinders psycho-physiological restoration and increases the level of stress. However, it cannot be excluded that some people that are under stress or strain for other reasons than wind turbine sound more easily react negatively when exposed to the

sound and hence become annoyed. Further studies will be needed to distinguish between the two directions of cause and effect.”

Should we wait until sufficient research has been undertaken on the psychological effects of wind turbines or should we take stock of the many warning signs that are emerging and call a halt on all wind turbine placements until proper controlled research is carried out? I advocate the latter, with this viewpoint entrenched in what is known as the precautionary principle:

“The precautionary principle is a moral and political principle which states that if an action or policy might cause severe or irreversible harm to the public, in the absence of a scientific consensus that harm would not ensue, the burden of proof falls on those who would advocate taking the action”

I recommend that discretion be given to adopting the precautionary principle given both the present state of scientific knowledge and the potential health impact the wind turbine complex may have on those residing in the general area. The WHO⁵ states:

“When there is a reasonable possibility that the public health will be endangered, even though scientific proof may be lacking, action should be taken to protect the public health, without awaiting the full scientific proof.”

and from others⁶⁷:

“No new industrial process should be imposed on an unsuspecting public without having been thoroughly, publicly, and independently studied beforehand. Only after such studies show that industrial WTi projects do not introduce risks to the health or safety of the target communities should they be permitted to proceed. If the studies show there are risks, then the next step is to determine what is needed to prevent them.”

which supports the adoption of the precautionary principle in the interests of public health.

In *McIntyre v Christchurch City Council* (1996:RMA 289) the precautionary principle was described thus:

“The influence of the general precautionary principle on the evaluation and ultimate judgment is a matter of discretion. None of the cases supports the application of a formal threshold. Like all elements that contribute to ultimate judgment, the weight to be given to the precautionary principle would depend on the circumstances. The circumstances would include the extent of present scientific knowledge and the impact on otherwise permitted activities”

13. CONCLUSION

There exists compelling evidence attesting to the impact that community noise can have on health. A number of interacting factors combine to determine an individual's response to noise. As such, noise level should not be used as the sole metric with which to judge the potential health effects of noise. Annoyance can lead to degraded health, quality of life and impaired sleep, while disrupted sleep can lead directly to severe health deficits. Noise sensitive individuals are more susceptible to the negative effects of community noise. Turbine noise is a type of community noise, and likewise has the potential to impact health and wellbeing, and evidence to this effect now exists in the peer reviewed literature.

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14. ABOUT THE AUTHOR

Daniel Shepherd received a PhD in psychoacoustics from the University of Auckland, New Zealand, in 2005. Since this time he has attained the position of Senior Lecturer at the Auckland University of Technology, where he lectures in the Faculty of Health in addition to being the Head of Postgraduate Studies in the School of Public Health and Psychosocial Studies. He is an Honorary Research Fellow at the University of Auckland, where he has researched and taught in the Departments of Psychology, Chemistry, and Audiology. The central theme of Daniel's research is the human response to sound, both audiometrically and psychometrically. Past and current research projects, many of them published in academic journals, include new methods in audiometric assessment; the quantification of noise sensitivity and noise annoyance; the relationship between noise sensitivity and quality of life; the development of a model of noise-induced stress; the electrophysiological characteristics of noise sensitive individuals, and; the psychological and physiological determinants of noise sensitivity. Dr Shepherd has represented and consulted with a number of community groups faced with intrusive noise, and argues that noise in the community must be managed with care if it is not to become a health risk.

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