Source: Wind Farm Noise Measurement, Assessment, and Control (Wiley)

In addition to the effects of audible wind farm noise on people, there is an ongoing debate and controversy on the physiological effects of infrasound. Nussbaum and Reinis (1985) published a report on human response to infrasound, reviewing a large amount of previously published work on the subject. The literature review provided many demonstrations of adverse effects of infrasound for short exposures at levels well above those produced by wind farms. Nussbaum and Reinis (1985) exposed 80 test subjects to two infrasound signals based on an 8-Hz tone at a total level of 130 dB for 30 min. The first signal had no higher-order harmonics while the second was rich in higher-order harmonics. The higher level of harmonics was found to be associated with headache and fatigue, while reduction in the harmonics resulted in symptoms of dizziness and nausea. They found that the reaction to infrasound varied considerably between individuals, most probably as a result of the inner ear structure or 'central adaptive mechanisms'. Some individuals exhibited symptoms that closely resembled motion sickness. With one exception, subjects reporting dizziness and nausea for the signal with no higher-order harmonics, experienced the symptoms hours later, after the experiment ended, but had raised respiratory rates during the experiment, which is consistent with vestibular system activation. Conversely, all subjects reporting only headache and fatigue noted these symptoms during the exposure, with headaches lasting up to 5 h beyond the exposure and fatigue lasting 15 h. No control subject reported any symptoms, thus validating the experiment.

Although there is no controversy on the adverse effects of short-duration exposures to relatively high levels of infrasound, there remains considerable controversy on the long-term effects of *periodic* infrasound at levels below the threshold of hearing. On the one hand some practitioners contend that infrasound should be ignored because wind farms produce infrasonic levels well below the hearing threshold so that noise levels are adequately documented using the A-weighting filter (see Section 2.2.11). On the other hand, a different perspective has been presented by Salt and Lichtenhan (2014) and co-workers. They have published a number of peer-reviewed articles on the effects of low-frequency noise and infrasound on the hearing mechanism and its physiology. They reported on a person suffering from Ménière's disease, who had her symptoms of vertigo, dizziness and nausea severely exacerbated when she was in the vicinity of wind turbines. People with this disease suffer from the condition called *endolymphatic hydrops*, in which the sensory organ can be displaced, thus obstructing the pressure relief opening at the apex of the cochlea (the helicotrema), resulting in a substantial increase in the low-frequency hearing response (by up to 20 dB) and symptoms of unsteadiness, vertigo, nausea (or seasickness), tinnitus and pressure fullness in the ear. Salt and Lichtenhan (2014) have suggested that hydrops can be developed in otherwise normal people when they are exposed to low-frequency noise or infrasound (based on experiments with short-term exposures to 50-Hz sound) and they have shown for these people the condition of hydrops resolves when they are no longer stimulated by low-frequency noise or infrasound. This is consistent with the relief from symptoms that wind farm noise sufferers experience some time after they leave the vicinity of a wind farm. No data are available on the effect of this condition on long-term exposure to low levels of infrasound, such as experienced by residents living near wind farms.

The ear is most sensitive to low-frequency noise and infrasound when audible noise in the 150–2000 Hz range is at a very low level or absent (Salt and Lichtenhan, 2012). This is because higher audible ambient background noise automatically causes the hearing threshold to be raised, thus protecting the ear against very high sound pressure levels. This is the reason why, in quiet environments such as in rural bedrooms, people can be maximally affected by infrasound: it is not attenuated much by the housing structure, whereas noise above 150 Hz is generally substantially attenuated. On the other hand, people in towns and cities have a raised low-frequency and infrasound hearing threshold as a result of other ambient noise, such as produced by traffic, and thus they are able to tolerate infrasound at levels that may cause problems to a rural resident. A study by Pedersen et al. (2010) showed that road traffic noise can also provide an additional effect of significant masking of wind farm noise, but only if the wind farm noise is between 35 and 40 dBA (L_{Aeq}) and not for higher or lower level wind farm noise. Masking only occurs when the road traffic noise is approximately 20 dBA or more louder than the wind farm noise.

Bell (2011), (2014) has also contributed some enlightened understanding to the debate, based on the physiological mechanism of how the ear hears (see Section 7.3). He explains how the middle ear acts continuously to position the eardrum in the middle of its operating range, while at the same time pushing or pulling on the oval window of the cochlea, thus increasing or decreasing the fluid pressure in the cochlea, which affects the gain of the hearing system. This gain control is an essential part of the ear having a dynamic range of over 120 dB (1 million to 1 in terms of pressure). The ear drum acts linearly to sound pressure, irrespective of the frequency, so that a 1-Hz sound at 70 dB has the same effect as a 1000-Hz sound in terms of affecting the middle ear muscle action in adjusting the ear drum position and cochlear pressure, even though the 1-Hz sound will be inaudible to the cochlea. Infrasonic sound in the range below 8 Hz is sensed as a series of impulses, corresponding to the peaks in sound pressure, rather than as a continuous stimulus, so in terms of the effect of infrasound on people, the peak of the signal is more important than the RMS value. Having the middle ear muscles acting every time they sense a peak pressure (which can be several times a second for infrasound) may lead to annoyance and a feeling of pressure in the ears of some people, and can result in serious sleep disturbance, even though the sound causing the problem is inaudible. As pointed out by Bell (2014), the level of infrasound needed to affect the operation of the middle ear is much lower than the level required for detection by the cochlea. In some people, it is possible that the action of the middle ear muscles in response to infrasound will increase the intralabyrinthine fluid pressure to a level sufficient to affect the balance organs of the inner ear and cause vertigo. People with Ménière's disease have episodes where they suffer vertigo and pressure fullness in their ears, and lose their balance. These effects may be attributed to a spasm in the middle ear muscles, increasing the intralabyrinthine fluid pressure beyond normal levels, in a similar way that exposure to low-level infrasound could affect some otherwise normal people.

In an interesting contribution to the debate, Swinbanks (2015a) pointed out that problems with low-frequency noise and infrasound from wind farms are most likely to manifest indoors rather than outdoors. This is because noise generated by pressure