Fourth International Meeting on Wind Turbine Noise

Rome Italy 12-14 April 2011

Selection of outcome measures in assessing sleep disturbance from wind turbine noise

Christopher Hanning and Michael Nissenbaum

University Hospitals of Leicester, UK and Northern Maine Medical Center, USA.
chrisdhanning@rockuk.net and mnissenbaum@att.net

Abstract

Dose response relationships have been commended as an appropriate tool in determining safe levels of wind turbine noise. Sleep disturbance is a major concern and the probable source of most of the claimed health consequences. Most studies to date have relied upon subjective reports of recalled awakenings or difficulty in initiating sleep. Arousals, brief lightening of sleep, are much more common than recalled awakenings and are not remembered. Arousals fragment sleep making it unrefreshing and of poor quality. Relying on recalled sleep disturbances will underestimate the impact of wind turbine noise.

Arousals may be detected electrophysiologically, from secondary cardiovascular effects or body movements. All of these measures require instrumentation and multiple nights of recording. While useful in investigating causation in sleep and health complaints, individual variability in response to sleep fragmentation undermines their utility as outcome measures

The purpose of sleep is ensure wakefulness and appropriate daytime functioning. Measures of sleepiness, fatigue and sleep quality which assess the actual restorative function of sleep could be appropriate outcome measures. Questionnaires are commonly used in sleep medicine and correlate well with laboratory measures. The Pittsburgh Sleep Quality index is widely used and is sensitive enough to detect changes with treatment. The Epworth Sleepiness Score measures average sleepiness and has been widely used to assess changes with therapy and population studies. As short questionnaires, they may be self-administered or delivered by relatively unskilled personnel and are available in a variety of different languages.

Data will be presented from studies of operating wind farms confirming that these measures are suitable outcome measures for the construction of dose-response relationships between wind turbine noise and effects on human sleep and health.

Introduction

A common feature of virtually all anecdotal and research reports of adverse health effects of industrial wind turbines (IWT) is sleep disturbance (Hanning 2010). All government sponsored reviews of noise and health focus on the effect on sleep and the majority of regulations governing the installation of IWT acknowledge the importance of preserving sleep and commonly, but not always, impose lower external noise limits during night time hours.

A number of government bodies have commended the use of dose-response relationships in judging the effects of noise on human health (eg, Berry and Flindell 2009, Verheijen 2009) and these would seem to be an appropriate tool for determining external IWT noise levels and/or setback distances. However, the selection of the appropriate outcome measure is key. Ideally, it should be a sensitive, robust, easily and economically measured parameter which integrates all possible effects of IWT noise on sleep.

While sleep physiologists have actively contributed to the study of the effects of road, rail and aircraft noise, they do not, thus far, seem to have contributed to the study of IWT noise. The purpose of this paper is to review sleep disturbance from a sleep medicine perspective and to suggest appropriate outcome measures for evaluating the effects of IWT.

Sleep Physiology

Sleep was previously regarded as a time of bodily restoration but current thought is that it is of the brain and for the brain and concerned primarily with the consolidation and storage of memory. To be refreshing and restorative, human sleep must be adequate both for duration and quality. The consequences of sleep deprivation include daytime sleepiness and fatigue, impaired concentration, memory and learning, low mood and impaired psycho-social functioning. Road accident rates are increased and employment prospects impaired. Obesity, increased risk of diabetes, high blood pressure, cardiovascular disease and cancer risk have been reported also. The short term consequences of sleepiness and fatigue are not trivial, having as much effect on quality of life as epilepsy and diabetes.

Sleep is not a unitary state, it comprises slow wave sleep (SWS) and rapid eye movement (REM) sleep. The former is characterised by a decreased frequency and increased amplitude of the EEG (brain electrical activity). Four levels of increasing depth are recognised (1-4). Stage 2 is the first level of true sleep and is characterised by spindles, short bursts of 12-14 Hz waves with a duration of 0.5-1.5 seconds. The spindle density (number/hr of sleep) is a marker of the ease with which sleep can be disturbed (Dang-Vu 2010). Spindle density decreases with age and is lower in some individuals, a trait which seems to be inherited. Arousals, brief increases in EEG frequency which may be sufficient to effect a change to a lighter level of sleep, occur both spontaneously and in response to internal (snoring, leg twitching) and external stimuli (noise, light, touch). The likelihood of an arousal occurring in response to a noise depends not just upon the depth of sleep, sound pressure and individual propensity but also upon frequency (Bruck 2009) and meaning, for example our name rather than a non-specific noise or a baby's cry. A sufficient stimulus may cause an awakening. The transition between sleep and wakefulness is a process and transfer of information from short-term to long-term memory is the last to return on wakening and vice-versa. Short awakenings, less than c30sec, are thus not recalled.

Sleep is organised into a series of cycles, each lasting about 90mins. The first two cycles comprise predominantly deep SWS. Each cycle ends with REM sleep. As the night progresses, the cycles comprise mainly Stage 2 SWS and REM sleep. Awakenings occur commonly between cycles, particularly the later cycles and will be recalled if long enough.

Arousals and awakenings are usually accompanied by an autonomic arousal, increased heart rate and blood pressure, which is thought to be the cause of the daytime high blood pressure in those with multiple arousals, for example obstructive sleep apnoea.

Effects of IWT noise on human sleep

The most obvious means for IWT noise to disturb sleep is to prevent the onset of sleep or the return to sleep following an awakening, either spontaneous or induced. At least 15% of the population are not robust sleepers and are easily disturbed. It is easy to dismiss this as an entirely psychological response but there is good evidence that this is largely an hereditable trait and therefore not just a result of attitude to IWT or perceived benefit (Shepherd 2010). The noise sensitive tend to be found in quieter rural areas. This response is very likely related to “annoyance” and the consequent stress with IWT noise. There is no doubt that IWT noise is much more annoying than rail, road and aircraft noise at the same sound pressure levels (Pedersen 2004, van den Berg 2008). WHO (2009) and EEA (2010) night noise guidelines are predicated largely on annoyance responses indicating that these organisations do not regard annoyance as trivial.

While there are as yet no studies confirming increased arousals secondary to IWT noise, as they have been found with all other environmental noise sources, there can be no doubt that they do occur. In addition, not all subjects reporting sleepiness, fatigue and other symptoms report recalled awakenings further supporting the conclusion that IWT noise causes arousals. The impulsive nature of IWT noise and the large low frequency component may be contributory.

Detection and measurement of sleep disturbance

Inadequate sleep duration due to delayed sleep onset or wakefulness during the sleep period is usually readily apparent to the individual. Simple diaries may suffice although a more objective measure may be obtained by actigraphy. These inexpensive wristwatch sized devices are worn on the non-dominant wrist and record movement for periods of up to 6 weeks and are thus suitable for field studies. Wakefulness and sleep can be distinguished with reasonable accuracy from the movement pattern. Arousals are often accompanied by brief movements and these can be inferred also.

The “gold standard” for assessment of human sleep is polysomnography (PSG), the recording of multiple electrophysiological, respiratory and cardiovascular signals. It is time-consuming and expensive, requiring skilled technicians. While it possible to undertake recordings in a subject’s home, it is better suited to laboratory based studies investigating the mechanisms of sleep disturbance and noise.

While arousals may be detected by PSG and by actigraphy, many studies rely on detecting the autonomic response. Heart rate changes may be measured easily and inexpensively either by chest electrodes (ECG) or from a peripheral pulse monitor. Absolute blood pressure is more difficult as the cuff based methods themselves cause an arousal as the cuff inflates. Relative blood pressure changes can however be inferred from the time delay between heart contraction (ECG) and the pulse wave arriving at the finger, the pulse transit time (PTT). This technology is widely used for the home assessment of patients with obstructive sleep apnoea who may have several hundred arousals due to airway obstruction each night.

However, it would seem to be more logical to assess the overall effects of sleep disruption by considering daytime functioning. It has been said that we sleep to stay awake and stay awake in order to sleep. It is reasonable also to conclude that, in general, sleep disruption is of little or no consequence if it does not effect daytime functioning. The major exception to this rule is where there are cardiovascular effects as they may be largely symptomless. Sleep clinicians not infrequently meet patients who seem to have major sleep disruption but deny any daytime consequences. Measures of the well established consequences of sleep deprivation are therefore appropriate.

The “gold standard” methods for measuring daytime sleepiness use PSG to determine sleep onset under standardised conditions (Multiple Sleep Latency Test or Multiple Wakefulness Test) but again, these are expensive and time consuming. Vigilance tests such as the OSLER (Bennett 1997) are simpler and relate well to the PSG based tests but are still essentially laboratory tools. Questionnaires are widely used in sleep medicine and the Epworth Sleepiness Score (ESS) (Johns 1991) has proved particularly effective and is universally accepted being translated into around 40 languages. Subjects are asked to rate their likelihood of falling asleep in eight situations on a 0-3 scale (0;never, 1;slight chance, 2; moderate chance, 3: high chance). Scores therefore range from 0-24. Normal subjects typically score 2-5, insomniacs scoring lower. Scores >10 are deemed excessive daytime sleepiness and are regarded as pathological, However, there is a wide range found among “normal” subjects although whether this represents the normal range or whether some of these subjects are sleep deprived is open to conjecture. In the absence of clinical change, scores are generally stable.

The ESS correlates well with the more objective measures of sleepiness and is commonly used as an outcome measure in pharmaceutical studies. It therefore would seem to be a suitable tool for the assessment of IWT noise. Nissenbaum and colleagues used the ESS in a study of IWT effects presented at this meeting. There were significant differences in mean ESS score between those living close to the turbines and those living further away. A plot of ESS score against distance from turbines showed a good relationship with ESS scores increasing sharply from 2000-400m.

Vigilance and psychomotor performance can be assessed by a number of simple tests which could conducted in the field rather than the laboratory. Elmenhorst and colleagues (2008, 2010) used the psychomotor vigilance task (PVT) and a memory search task in a study of the cognitive effects of exposure to aircraft noise. The study showed a clear link between noise levels and PVT decrements down to night-time LAeq noise levels of 32dB(A). This methodology should therefore be applicable to studies of IWT also.

A number of questionnaires have been published with the intention of providing an overall assessment of sleep quality. The Pittsburgh Sleep Quality Index (PSQI) (Buysse 1989) has proved to be robust and reproducible and has been widely used in surveys, pharmaceutical and therapeutic studies (for example, Morgan 2004). It is available in over 50 languages. 10 questions, most with sub-sections, explore most aspects of sleep and daytime functioning. Analysis is straightforward using on-line tools. Poor quality sleep is defined as a score >5. Nissenbaum and colleagues used the PSQI in a study of IWT effects presented at this meeting. Those living close to the turbines had greater mean PSQI scores ($p<.05$) and were more likely to have a PSQI >5 ($p = 0.07$) than those living further away. A plot of PSQI score against distance from turbines showed a good relationship with PSQI scores increasing sharply from 2000-400m.

Conclusions

Self reported sleep disturbance is an inappropriate outcome measure for assessing the effects on sleep of IWT noise. While technologically based measures may be helpful in investigating causation and in confirming causal relationships, simple questionnaires such as the PSQI and ESS provide an inexpensive and effective means of assessing the effects of IWT noise on sleep and merit further research.

References

Bennett LS, Stradling JR, Davies RJ. A behavioral test to assess daytime sleepiness in obstructive sleep apnoea. J Sleep Res 1997;6:142–145

van den Berg G P., et al. 2008. WINDFARMperception. Visual and acoustic impact of wind turbine farms on residents. FP6-2005-Science-and-Society-20. Specific Support Action Project no. 044628

Berry B and Flindell I. 2009. Estimating Dose-response relationships between noise exposure and human health impacts in the UK. Final Project Report BEL 2009-001. Berry Environmental Ltd (BEL).

Bruck D et al. 2009. How does the pitch and pattern of a signal affect auditory arousal? Journal of Sleep Research 18:196-203

Buysse,D.J., Reynolds,C.F., Monk,T.H., Berman,S.R., & Kupfer,D.J. 1989. The Pittsburgh Sleep Quality Index (PSQI): A new instrument for psychiatric research and practice. Psychiatry Research, 28(2), 193-213.

Dang-Vu et al. 2010. Spontaneous brain rhythms predict sleep stability in the face of noise. Current Biology. 20:R626-7.

Elmenhorst E, Basner M. Effects of Nocturnal Aircraft Noise (Volume 5): Performance. Institute of Aerospace Medicine of the German Aerospace Center (DLR), Cologne. DLR-Forschungsbericht 2004-11

Elmenhorst EM, Elmenhorst D, Wenzel J, Quehl J, Mueller U, Maass H, Vejvoda M, Basner M. 2010. Effects of nocturnal aircraft noise on cognitive performance in the following morning: dose-response relationships in laboratory and field. Int Arch Occup Environ Health. 2010 Oct;83(7):743-51.

European Environment Agency 2010. Good practice guide on noise exposure and potential health effects. ISSN 1725-2237

Hanning CD. 2010. Wind turbine noise, sleep and health. Society for Wind Vigilance. http://www.windvigilance.com/noise_sleep_health.aspx

Johns MW. 1991. A new method for measuring daytime sleepiness: the Epworth sleepiness scale. Sleep;14:540–545

Morgan K, Dixon S, Mathers N, Thompson J and Tomeny M. 2004. Psychological treatment for insomnia in the regulation of long-term hypnotic drug use. Health Technology Assessment; Vol. 8: No. 8 http://www.hta.ac.uk/fullmono/mon808.pdf

Pedersen E and Persson Waye K. 2004. Perception and annoyance due to wind turbine noise—a dose-response relationship J. Acoust. Soc. Am. 116 3460–347

Shepherd D. 2010. Wind turbine noise and health in the New Zealand context. In: Rapley, B. I. and Bakker, H. H. C., Sound, Noise, Flicker and the Human Perception of Wind Farm Activity. Atkinson & Rapley Consulting Ltd, Palmerston North, New Zealand. ISBN 978-0-473-16558-1.

Verheijen E et al. 2009. Evaluatie nieuwe normstelling windturbinegeluid. RIVM-rapport 680300007/2009

World Health Organisation. 2009. Night noise guidelines for Europe. Copenhagen.