Exhibit N

Wind turbines, flicker and photosensitive epilepsy: Characterising the flashing that may precipitate seizures and optimising guidelines to prevent them.

*Graham Harding, *Pamela Harding and †Arnold Wilkins
*Neurosciences Institute Aston University, Birmingham, England and †Department of Psychology University of Essex, Colchester, England.

Running title = Wind turbine Flicker & photosensitive epilepsy
Keywords: photosensitive epilepsy, flicker, rotors, visual discomfort, wind farms, wind turbines, green power.

Corresponding Author: Professor Graham Harding
The ElectroDiagnostic Centre Ltd, Greenfields, Upton Snodsbury, Worcester WR7 4NR,UK
Telephone & Fax: 01905 381 335
Email: gharding@wyenet.co.uk

Summary

Wind turbines are known to produce shadow flicker due to interruption of sunlight by the turbine blades. Known parameters of the seizure provoking effect of flicker, i.e., contrast, frequency, mark-space ratio, retinal area stimulated and percentage of visual cortex involved were applied to features of wind turbines. The proportion of patients affected by viewing wind turbines showed that seizure risk does not decrease significantly until the distance exceeds 100 times the height of the hub.

Since risk does not diminish with viewing distance, flash frequency is therefore the critical factor and should be kept below three per second, i.e., sixty revolutions per minute for a three-bladed turbine. On wind farms the shadows cast by one turbine on another should not be viewable by the public if the cumulative flash rate exceeds three per second. Turbine blades should not be reflective.

Introduction

The provision of energy from renewable sources has produced a proliferation of wind turbines. Environmental impacts include safety, visual acceptability, electromagnetic interference, noise nuisance and visual interference or flicker. Wind turbines are large structures and can cast long shadows. Rotating blades interrupt the sunlight producing unavoidable flicker bright enough to pass through closed eyelids, and moving shadows cast by the blades on windows can affect illumination inside buildings.

Planning permission for wind farms often consider flicker, but guidelines relate to annoyance and are based on physical or engineering considerations rather than the danger to people who may be photosensitive.

Photosensitive Epilepsy (PSE)

PSE occurs in one in 4,000 of the population (Harding & Jeavons 1994). The incidence is 1:1 per 100,000 per annum. Amongst 7-19 year-olds the incidence is more than five times greater (Fish et al 1993). Photosensitivity persists in 75 per cent of patients (Harding et al 1997).

Precipitants

Sunlight is a precipitant of photosensitive seizures, whether reflected from waves, or interrupted as the subject travels past an avenue of trees or railings. In 454 patients Harding & Jeavons (1994) found 33 cases where seizures had been precipitated by flickering sunlight.

Television is a common precipitant of seizures and guidelines now prevent the broadcast of programmes with flicker at rates exceeding 3 flashes per second, the frequency above which the chance of seizures is unacceptably high.

Flicker from rotating blades

The interruption of light by helicopter blades has caused seizures (Johnson 1963, Gastaut & Tassinari 1966, Cushman and Floccare 2007) but to our knowledge there are no reports of seizures induced by rotating ceiling fans.

Large wind turbines usually rotate at between 30 and 60 revolutions per minute (rpm). Many are three-bladed and operate at a constant speed, and at 60 rpm produce flicker at a rate of 3Hz; some two bladed wind turbines also exist. Turbines that rotate faster or have more blades will produce flicker at frequencies for which the chances of seizures are unacceptably high. Smaller variable-speed turbines range between 30 and 300 rpm (Verkuijlen & Westra 1984) and some have more than three blades, so their flicker is within the range for which seizures are likely.

When several turbines are in line with the sun's shadow there is flicker from a combination of blades from different turbines which can have a higher frequency than from a single turbine.

If the blades of a turbine are reflective then there is the possibility of flicker from reflected light at viewing positions that are unaffected by shadows.

Exposure to flicker from a turbine is determined by the hub height and the diameter of the blades, the height of the sun and the direction of the blades relative to the observer. These variables are affected by the time of day, time of year, wind direction, and geographical location (Verkuijlen & Westra 1984). Shadows can be cast on the windows of nearby buildings, affecting the internal illumination giving rise to flicker that cannot be avoided by occupants. Verkuijlen & Westra determined the shadow tracks of wind turbines and their effect relative to the hub height of the rotor. They assumed that the rotor diameter was 75 per cent of the hub height, but many wind turbines deviate from this ratio.

To avoid the problems of shadow flicker Verkuijlen and Westra proposed that wind turbines should only be installed if flicker frequency remains below 2.5 Hz under all conditions, and that wind turbines should be sited where buildings were not in East-NE or WNW directions from the turbine (northern hemisphere recommendations).

Modelling the effects of flicker

1. Shadow flicker

The seizure provoking effects of flicker depend on the time-averaged luminance of the flicker, its contrast, frequency and mark-space fraction, and the area of retina stimulated and are well described (Figure 1).

INSERT FIGURE 1 ABOUT HERE

The area of retina stimulated by flicker from a wind turbine might be expected to depend on the area that the rotors subtend at the eye. However, if the rotors interrupt direct sunlight casting a shadow upon the observer then the luminance of the flicker is likely to be such as to scatter sufficient light within the eye as to stimulate the entire retina with intermittent light. If the eyes are closed, the light is diffused by the eyelids and intermittent light reaches the entire retina.

The luminance contrast ratio of the flicker depends on the extent to which the blades occlude the sun. Given that the sun subtends about 0.5 degrees, it is only completely occluded when the blades subtend more than 0.5 degrees at the eye, ignoring flare. When the observer is at a distance at which the blades subtend less than 0.5 degrees, the contrast of the flicker is reduced. Flicker ceases to be provocative at luminance contrasts less than about 10%, see Figure 1. Assuming that contrasts of less than 10% occur when the width of the turbine blade subtends at the eye an angle that is 10% of the sun's diameter (0.05 degrees) it is possible to set a limit for the distance at which shadow flicker is likely to be seizure provoking. For a turbine blade 1m in width, this distance is 1.14km. Most shadows are likely to be of contrast sufficient to be provocative. It may be insufficient to restrict the siting of turbines to a distance ten diameters from habitation (Clarke).

In EEG laboratories epileptiform EEG activity is induced in photosensitive individuals by a xenon gas discharge lamp providing a series of very brief flashes. ,ie,Laboratory studie,s have not investigated the effect of very brief dark periods in an otherwise bright stimulus (such as might be provided by a wind turbine rotor) However in the case of a seizure induced by helicopter blades reported by Cushman and Floccare (2007) the dark period of the shadow flicker occurred between 24 and 27 times per second. Helicopter blades are usually narrower than those on wind turbines and would provide for a shorter dark interval that might be expected to be less provocative than for a wind turbine blade.

2. Reflected flicker

Flashing can occur by the reflection of sunlight from the gloss surface of blades (Clarke). The blades are likely to cause flicker only if the amount of sun reflected towards an observer varies with the rotation of the blades. Given the shape of the blades, such variation is likely. These considerations introduce the possibility of a danger zone different from than that provided by the shadow cast by the blades.

In the case of reflected sunlight, the flicker may be less bright than that cast by a shadow, and the light scattered within the eye may be insufficient to cause a problem. If so, the effectiveness of the stimulus will depend on the visual angle subtended by the rotor at the observer's eye. This visual angle will be directly proportional to the rotor length (radius) and the distance from which the observer is viewing the rotor.

The visual angle subtended by the flickering light determines the likelihood of seizures. From the studies of Binnie, et al (2002) or Wilkins et al (2005) it is clear that the risk of seizures is in direct proportion to the area of visual cortex stimulated, see Figure 1. For this reason, flicker that is directed at the centre of the visual field is more provocative than flicker in the visual periphery. (The central 10 degrees of vision provide for 90 per cent of the neural output from the retina to the brain.)

INSERT FIGURE 2 ABOUT HERE

Suppose a turbine with blades 75% of hub height is viewed from a distance (Figure 2). The sunlight is not simultaneously reflected from more than one blade given that the angle of the blades relative to the sun will rarely be similar. We will assume that the blades are of uniform width equal to 10% of their (radial) length. The angle at the eye of an observer subtended by any blade is maximum when the blade is at the bottom of its path. Assuming gaze is centred half way up the blade the proportionate area of the visual cortex stimulated can be calculated. According to Drasdo (1977), the proportion of visual cortex (P) to which a circular centrally fixated stimulus, angular radius A, projects is:-

$$P = 1 - e^{-0.0574A}$$

Applying this formula to angular segments of the rotor surface centrally fixated, the area of cortex to which the rotor projects can be calculated and the proportion of patients liable to seizures can be estimated, using the relationship between proportion affected and stimulated area of the cortex (Figure 1). The proportion of patients affected is shown as a function of viewing distance (expressed as a factor of the height of the hub) (Figure 3). Note that the risk of seizures does not decrease appreciably until the viewing distance exceeds 100 times the height of the hub, a distance typically more than 4km.

INSERT FIGURE 3 ABOUT HERE

The above analyses indicate that flicker from wind turbines is potentially a problem at considerable observation distances.. Over 1km, only 25 per cent of the light is expected to be attenuated by the atmosphere (Curcio et al 1953). The effects of luminance on seizure risk are likely to depend on the logarithm of the luminance (Binnie et al, 2002), so any reduction of seizure risk by virtue of the atmospheric attenuation of light is likely to be small.

Discussion

Flicker from turbines that interrupt or reflect sunlight at frequencies greater than 3Hz poses a potential risk of inducing photosensitive seizures. At or below 3 Hz the calculated risk of inducing a seizure should be less than 2? in 133,000 of the photosensitive population. The risk is maintained over considerable distances from the turbine. It is therefore important to keep rotation speeds to a minimum, and in the case of turbines with 3 blades ensure that the maximum speed of rotation does not exceed 60rpm, which is normal practice for large wind farms. The layout of wind farms should ensure that shadows cast by one turbine upon another should not be readily visible to the general public. The shadows should not fall upon the windows of nearby buildings. The specular reflection from turbine blades should be minimised.

Acknowledgements

We confirm that we have read the Journal's position on issues involved in ethical publication and affirm that this report is consistent with those guidelines. None of the authors have any associations which might affect their ability to present and/or interpret data objectively, particularly financial ties to funding sources for the work under review.

References

Binnie,, C. D. Emmett, J. Gardiner, P. Harding, G.F.A. Harrison, D. and Wilkins A. J. (2002). Characterizing the flashing television images that precipitate seizures. SMPTE J. , August: 323-329

Clarke, A.D. A case of shadow flicker/flashing: Assessment and solution. Personal communication.

Curcio, J.A., Drummeter, L.F., Petty, C.C., Steward, H.S. and Butler, C.P. (1953). An experimental study of atmospheric transmission. J. Opt. Soc. Amer. , 43 (2): 97-102.

Cushman, J.T. and Floccare,D.J. (2007) Flicker illness: an under-recognized but preventable complication of helicopter transport. Prehosp. Emerg. Care 11, (1): 85-88

Drasdo, N. (1977) The neural representation of visual space. Nature 266(5602): 554-6.

Fish, D.R., Quirk, J.A., Smith, S.J.M., Sander, J.W.A.S., Shorvon, S.D., Allen, P.J. (1993) National Survey of Photosensitivity and Seizures Induced by Electronic Screen Games (Video Games, Console Games, Computer Games). Interim Findings, London: Dept of Trade & Industry.

Gastaut, H., Tassinari, C.A. (1966) Triggering Mechanisms in Epilepsy. The electroclinical point of view. Epilepsia. 7: 85-138.

Harding, G.F.A. & Jeavons, P.M. (1994) Photosensitive Epilepsy. MacKeith Press, London.

Harding, G.F.A., Edson, A., Jeavons, P.M. (1997) Persistence of Photosensitivity. Epilepsia, 38: 663-9.

Johnson, L. C. (1963) Flicker as a helicopter pilot problem. Aero. . Med. , 34: 306-310.

Verkuijlen, E., & Westra, C.A. (1984) Shadow Hindrance by Wind Turbines. Proceedings of the European Wind Energy Conference.

Wilkins, A.J., Emmett, J., & Harding, G.F.A. (2005) Characterising the patterned images that precipitate seizures and optimizing guidelines to prevent them. Epilepsia. 46: 1212-1218.

Figure 1

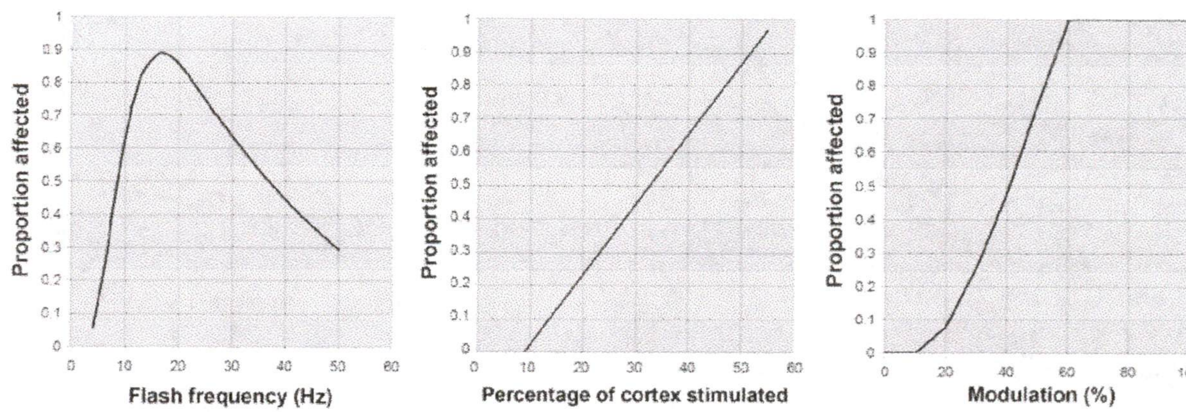

Figure 1. Proportion of patients with photosensitive epilepsy sensitive to flicker, shown as a function of the frequency, the proportion of the cortex to which the flicker projects (estimated from the response to striped patterns, and the modulation depth of the flicker (expressed as a Michelson fraction). The data are taken from Binnie, et al (2002).

Figure 2

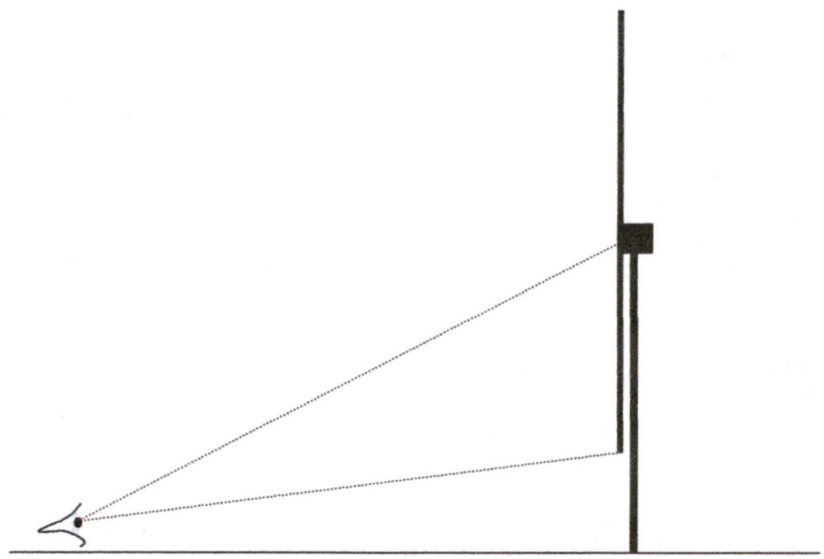

Figure 2. Maximum visual angle is subtended by blades when at the bottom of their path.

Figure 3

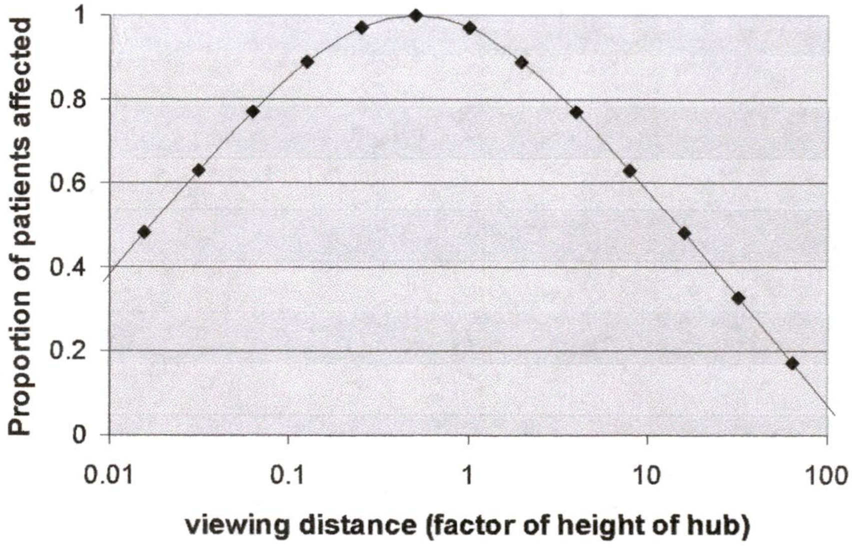

Figure 3. Proportion of photosensitive patients liable to seizures from light reflected from a turbine blade shown as a function of viewing distance. The viewing distance is given as a factor of the height of the hub.