Environment International 114 (2018) 160–166

Contents lists available at ScienceDirect

Environment International

journal homepage: www.elsevier.com/locate/envint

Short-term nighttime wind turbine noise and cardiovascular events: A nationwide case-crossover study from Denmark

Aslak Harbo Poulsen[a,*], Ole Raaschou-Nielsen[a,c], Alfredo Peña[b], Andrea N. Hahmann[b], Rikke Baastrup Nordsborg[a], Matthias Ketzel[c], Jørgen Brandt[c], Mette Sørensen[a]

[a] Diet, Genes and Environment, Danish Cancer Society Research Center, Copenhagen, Denmark
[b] DTU Wind Energy, Technical University of Denmark, Roskilde, Denmark
[c] Department of Environmental Science, Aarhus University, Roskilde, Denmark

ARTICLE INFO

Handling Editor: Martí Nadal

Keywords:
Stroke
Myocardial infarction
Wind turbines
Noise
Epidemiology

ABSTRACT

Aims: The number of people exposed to wind turbine noise (WTN) is increasing. WTN is reported as more annoying than traffic noise at similar levels. Long-term exposure to traffic noise has consistently been associated with cardiovascular disease, whereas effects of short-term exposure are much less investigated due to little day-to-day variation of e.g. road traffic noise. WTN varies considerably due to changing weather conditions allowing investigation of short-term effects of WTN on cardiovascular events.

Methods and results: We identified all hospitalisations and deaths from stroke (16,913 cases) and myocardial infarction (MI) (17,559 cases) among Danes exposed to WTN between 1982 and 2013. We applied a time-stratified, case-crossover design. Using detailed data on wind turbine type and hourly wind data at each wind turbine, we simulated mean nighttime outdoor (10–10,000 Hz) and nighttime low frequency (LF) indoor WTN (10–160 Hz) over the 4 days preceding diagnosis and reference days. For indoor LF WTN between 10 and 15 dB(A) and above 15 dB(A), odds ratios (ORs) for MI were 1.27 (95% confidence interval (CI): 0.97–1.67; cases = 198) and 1.62 (95% CI: 0.76–3.45; cases = 21), respectively, when compared to indoor LF WTN below 5 dB(A). For stroke, corresponding ORs were 1.17 (95% CI: 0.95–1.69; cases = 166) and 2.30 (95% CI: 0.96–5.50; cases = 15). The elevated ORs above 15 dB(A) persisted across sensitivity analyses. When looking at specific lag times, noise exposure one day before MI events and three days before stroke events were associated with the highest ORs. For outdoor WTN at night, we observed both increased and decreased risk estimates.

Conclusion: This study did not provide conclusive evidence of an association between WTN and MI or stroke. It does however suggest that indoor LF WTN at night may trigger cardiovascular events, whereas these events seemed largely unaffected by nighttime outdoor WTN. These findings need reproduction, as they were based on few cases and may be due to chance.

1. Introduction

As the number of wind turbines (WT) has increased so has concern about potential health effects, particularly since WT noise (WTN) has been reported to be more annoying than noise from other sources at similar levels (Janssen et al., 2011). Also, some (Schmidt and Klokker, 2014) but not all (Jalali et al., 2016; Michaud et al., 2016c) studies have found an association with sleep disturbances.

Noise can act as a stressor and provoke a typical stress response, including hyperactivity of the sympathetic autonomic nervous system and activation of the hypothalamus-pituitary-adrenal axis. Nighttime noise exposure is considered particularly hazardous (Babisch et al., 2005; WHO, 2009) and has been associated with disturbance of sleep, from full awakenings to unconscious autonomic perturbations, such as sleep stage changes and body movements (Griefahn et al., 2008; Miedema and Vos, 2007); the latter from outdoor noise levels of down to 30 dB (WHO, 2009). Nighttime noise exposure has been associated with reduced cardiac parasympathetic tone, high blood pressure, endothelial dysfunction, oxidative stress and increased levels of stress hormones shortly after noise exposure or on the morning after (Graham et al., 2009; Schmidt et al., 2013). Evidence from cardiac arousals does not suggest pronounced habituation to nighttime noise (Basner et al., 2011; Muzet, 2007). Long-term residential exposure to transportation noise has consistently been associated with increased risk of cardiovascular diseases (Halonen et al., 2015; Sorensen et al., 2011; Vienneau et al., 2015), whereas it is unknown whether short-term exposure to

* Corresponding author at: Danish Cancer Society Research Center, Strandboulevarden 49, 2100 Copenhagen, Denmark.
E-mail address: Aslak@Cancer.dk (A.H. Poulsen).

https://doi.org/10.1016/j.envint.2018.02.030
Received 10 October 2017; Received in revised form 1 February 2018; Accepted 17 February 2018

noise can trigger a cardiovascular event due to lack of studies (Recio et al., 2016). These results are, however, not readily applicable to WTN: WTN levels are typically lower than those reported in relation to health effects of traffic noise. and WTN is reported as more annoying than traffic noise at similar sound levels (Janssen et al., 2011). Also, WTs are typically erected in rural areas and amplitude modulation gives WTN a rhythmic quality different from that generated by car tires. Furthermore, levels of WTN depend on wind speed and direction and hence vary more unpredictably than road traffic noise, permitting investigation of acute effects of noise exposure. Such effects are virtually unexplored, even though factors affected by noise exposure, including increased blood pressure and oxidative stress, are believed to be important triggers of stroke and myocardial infarction (MI) (Biasucci et al., 2008; McColl et al., 2009).

Studies from Canada (1238 participants) and Sweden and the Netherlands (1755 participants) investigated associations between long-term outdoor WTN and self-reported cardiovascular diseases (high blood pressure and heart disease) (Michaud et al., 2016b; E Pedersen 2011). The study from Canada additionally investigated hair cortisol levels, resting heart rate and blood pressure collected at the time of interview (Michaud et al., 2016a). Neither study found any association. However, as most scientific literature on WTN (Schmidt and Klokker, 2014), the studies were cross-sectional, relied on self-reported data and had few participants potentially exposed to WTN levels above 40–45 dB. Also, their exposure metrics did not reflect day-to-day variations in WTN, making the results relevant mainly for long-term health effects.

Denmark is a densely-populated country with a high number of residents living close to WTs. This provides a unique opportunity to investigate acute effects of WTN on stroke and MI.

2. Methods

2.1. Study base and noise exposure assessment

The study was based on the Danish population, where all citizens since 1968 have been assigned a personal identification number by the Central Population Register, allowing residents to be tracked in and across all Danish health and administrative registers (CB Pedersen 2011).

We identified all WTs (7860) in operation in Denmark any time between 1980 and 2013, from the administrative Master Data Register of Wind Turbines maintained by the Danish Energy Agency. The register, to which reporting is mandatory for all WT owners, contained cadastral codes and geographical coordinates for each WT from the WT owner. For WTs in operation at the time of data extraction, the register also contained coordinates from the Danish Geodata Agency. In case of disagreement between the recorded geographical locations, the WT location was validated against aerial photographs and historical topographic maps of Denmark. We excluded 517 offshore WTs and 87 WTs for which a credible location could not be established. Moreover, 314 WTs wrongly recorded in the Master Data Register were assigned coordinates based on maps and aerial photographs. Information on height, model, type and operational settings (when relevant) was gathered for all WTs, based on which each WT was classified into one of 99 noise spectra classes detailing the noise spectrum from 10 Hz to 10,000 Hz in thirds of octaves for wind speeds from 4 to 25 m/s. These noise classes were formed from existing measurements of sound power for Danish WTs (details in (Backalarz et al., 2016; Søndergaard and Backalarz, 2015)).

For each WT location, we estimated the hourly wind speed and direction at hub height for the period 1982–2013, using mesoscale model simulations performed with the Weather Research and Forecasting model (Hahmann et al., 2015; Peña and Hahmann, 2017). From these simulations, we also extracted the temperature and the relative humidity at 2 m height as well as the atmospheric stability at each WT location.

The applied noise exposure modelling has been described in details elsewhere (Backalarz et al., 2016). In summary, we used a two-step approach. First, we identified buildings eligible for detailed noise modelling, corresponding to all dwellings in Denmark that could experience at least 24 dB(A) outdoor noise or 5 dB(A) indoor low frequency (LF, 10–160 Hz) noise under the unrealistically extreme scenario that all WTs ever standing in Denmark were simultaneously operating at a wind speed of 8 m/s with downwind sound propagation in all directions. In the second step, we performed a detailed modelling of noise exposure for the 553,066 buildings identified in step one: We calculated noise levels in 1/3 octave bands from 10 to 10,000 Hz using the Nord2000 noise propagation model (Kragh et al., 2001), taking into account time varying wind speed and direction, temperature, relative humidity and atmospheric stability. The model has been successfully validated for WTs (Søndergaard et al., 2009). For each dwelling, the noise contribution from all WTs within a 6000 meters radius was calculated hour by hour. For each night these modelled values were then aggregated over the period 10 pm to 7 am (nighttime), which is considered the most relevant time-window, because people are most likely to be at home as well as sleep during these hours. We calculated outdoor A-weighted sound pressure level at the front door of all buildings. We also calculated A-weighted indoor LF (10–160 Hz) sound pressure level for each dwelling using existing data on sound attenuation in this frequency range. All dwellings were classified into one of six sound insulation classes based on building attributes in the Building and Housing register (Christensen, 2011): “1½-story houses” (residents assumed to sleep on the second floor), “light façade” (e.g. wood), “aerated concrete” (and similar materials including timber framing), “farm houses” (remaining buildings in the registry classified as farms), “brick buildings” and “unknown” (assigned the mean attenuation value of the five previous classes). For each of the six classes, the frequency-specific attenuation values subtracted from the outdoor noise can be found elsewhere (Backalarz et al., 2016).

For each dwelling, we determined a validity score for the noise estimate for each night. This score summed up information for all contributing WTs on the number of measurements used to determine the WTN spectra class, and how closely the simulated meteorological conditions of each night resembled the conditions under which the relevant WTN spectra were measured.

2.2. Study population and identification of outcomes

From the Danish Civil Registration System (CB Pedersen 2011), we identified our study population defined as all adults ($\geq$18 years) living in a dwelling that had on two separate days over the period 1982–2013 experienced at least 1 h with outdoor WTN above 30 dB(A). The last criteria reduced the population while retaining all potentially high exposed. In this study population, we identified all diagnoses of stroke (International classification of disease (ICD) 10: I61, I63, I64 and ICD 8: 431–434 and 436) or MI (ICD 10: I21 and ICD 8: 410) from the Danish National Patient Register (Lynge et al., 2011) and the Danish Register of Cause of Death (Helweg-Larsen, 2011). We excluded outpatients and patients found dead, because an exact date of event could not be reliably established. Admissions separated by at least 28 days were counted as separate events. We additionally required no hospitalisation for any reason in the 28 days preceding diagnosis. Also, we excluded cases who, at the time of diagnosis, had lived < 18 months at their present address or if the closest WT had not been the same for the past 18 months (to ensure that any observed effect was unrelated to environmental changes from moving address or changes in nearby WTs).

The study was approved by the Danish Data Protection Agency (J.nr: 2014-41-2671). By Danish Law, ethical approval and informed consent are not required for entirely register-based studies not involving contact with study participants.