Wind turbine operation at officially permitted distances to residential areas is causal to severe sleep disorders in Germany: A descriptive cohort study

S. Kaula[1*], K. Nelson[1], E. Brunne[1], T.C. Stiller[2], J.Wagner[1], H.Timm[2]

Contact: E-mail: Dr.Kaula@gmail.com

Abstract

Background: Increasing numbers of serious adverse health effects reported by residents living near wind turbines served to initiate this descriptive cohort study.

Methods: Two physicians interviewed 131 persons across Germany who suspected that their health impairments were due to nearby wind turbine operation. A questionnaire completed by each interviewee provided the data for this report.

Results: Chronic sleep disorders connected to wind turbine operation were reported by 128 persons. A reproducible chronic sleep disorder (repeated temporal relationship between wind turbine operation and sleeplessness) was reported by 116 persons. When removed from wind turbine vicinity or windstill normal sleep ensued. Chronic severe sleep disturbance was described by 103 persons, accompanied by symptoms including daytime fatigue, difficulty concentrating, performance decline, depression, irritability, anxiety, restlessness and psychosocial and/or work performance impairment. Twenty persons left their homes nightly to sleep farther away from the wind turbines, 27 moved away and 9 plan to move away. In 53 cases adverse health effects were first experienced after repowering, where smaller wind turbines were replaced with larger ones.

Conclusions: Chronic, severe sleep disorders are related to wind turbine operation. Repowering with larger wind turbines often initiated the sleep disorders.

Introduction

General practitioners in Germany have noted an increase in the number of patients residing near wind turbines complaining of diverse adverse health effects. Patients report that their complaints disappear on windless days or vacationing far from operating wind turbines. The diagnosis code ICD-10-GM-T72.5 (effects of vibration, vertigo due to infrasound), which is billable, is noted when vertigo is the complaint. To date complaints by residents near wind turbines who experience adverse health effects and seek relief are relegated by authorities to tolerable annoyance and cases are considered annecdotal. The position of the Federal Environmental Agency is that operation of wind turbines at permitted distances to nearby residents does no damage to health [1].

Over 30,000 wind turbines make Germany the country with the highest on land wind turbine density worldwide and wind turbine size has approximately doubled over the past 20 years. The size increase results in the generation of more electricity through the increased area swept by longer

rotor blades and stronger, more steady wind at greater height. However, each blade passage past the turbine tower generates infrasound whose level increases with increasing rotor blade-length [2]. In 2007 the Robert Koch Institute advocated optimizing infrasound measurement to implement epidemiological studies quantifying possible effects of long-term exposure to infrasound [3]. Physicians for Immission Protection (Aefis) [4] and a recently released open letter from experts to policy makers [5] have also addressed this issue. Despite these advocations, substantial research into health risks associated with wind turbine operation is still lacking. This deficiency has been rationalized: "… those countries with the largest wind farm operators in the world display little ambition to do research into health risks." [6]
Since no central registry exists and authenticity of reported health complaints in connection with wind turbine opertion are often doubted, we as family physicians undertook to document cases by video and make them, providing consent, available online. Physicians informed their patients of this opportunity and the number of participants willing to supply video documentation soon exceeded the capacity of the documentarians. Questionnaires were then issued to collect information in a standardized manner from persons strongly affected by wind turbine operation. Data compiled from these questionnaires serve as the data set for this study.

Methods

Study sites and participants
From Nov. 2018 – Feb. 2020, a descriptive cohort investigation based on a questionnaire (supplement-1) was carried out on persons sensing that their adverse health effects were due to wind turbine operation near their residences. No exclusion criteria were implemented except for apparent psychological illness, applicable in one case. The age range of participants was from school age to over 80 years. Wind turbines had been erected at lawfully permitted distances, such that the interior sound level inside residences was below 35 dB(A) during the day and 25 dB(A) during the night (10 p.m. – 6 a.m.), as specified by the German Technical Guidelines to Protect Against Noise (TA-Lärm) [7].

Video documentation
We used onsite freely narrated video documentation to demonstrate authenticity in approximately half of the cases, or if necessary, through prompting by a physician (S.K. or H.T.) asking about the person's sleeping behavior, reproducibility, and whether the person associated any psychosocial effects with wind turbine operation. Each video was shortened to about 10 minutes and, if consent was provided, made available online [8].

Questionnaire
After video documentation exceeded documentary capacity we issued a questionnaire to participants who had learned of the documentation through their physician, had seen the videos online or been informed by earlier participants about the possibility of participating in the investigation. The data presented in this study stems from the questionnaire, completed by each participant, including those who had participated in video documentation. Most questionnaires were submitted online, only in those few cases where this was not possible were they completed by telephone.

Assessment of sleep disorders

Sleep disorders, one of the most common complaints associated with wind turbine operation [9], were the main focus. A sleep disturbance was considered reproducible if experienced at least twice, with a cycle of appearance in temporal relationship with wind turbine operation (wind blowing) and disappearance with wind calm, parked wind turbines or traveling out of the sphere of wind turbine influence. Standard questions included queries about complaints unrelated to sleep, pre-existing

conditions regarding the complaints, family members and neighbors, and abnormalities observed in wild or domestic animals. A query was also posed about attitude towards wind energy before suspicion arose that wind turbine operation might be related to adverse effects to health.
We determined sleep disorder severity according to the S-3 guidelines 'Non-restful sleep/sleep disorders' (Table 1) of the German Society for Sleep Research and Sleep Medicine (DGSM) [10].

Statistical analysis

All data was obtained from the questionnaires. Quantitative data are expressed numerically. Qualitative data in regard to a possible correlation between severity of sleep disturbance (severity scale 1-3: 1=low, 2=moderate, 3=severe) and distance to nearest wind turbine was checked with the Spearman's rank correlation coefficient [11].

Results

Sleep disturbance
Of the 131 cases documented by completed questionnaire (Table 2), 81 persons were visited and interviewed by a physician and 54 of these permitted video-documentation. Portrayals were dramatic, reflecting intense suffering, and many of those affected had abandoned their homes (27 moved away and 9 plan to move away) or nightly drove farther away from the wind turbines to be able to sleep (20 persons). As a rule, people with reproducible sleep disorders experienced them many times over, and so were much more frequent than only twice. A chronic sleep disorder [12] connected to wind turbine operation was reported by 128 persons, 25 cases of low and moderate severity and 103 of high severity. A weak to moderate indirect relationship between the severity of the sleep disturbance and the distance to the nearest wind turbine was apparent (Fig 1, $\rho = -0.15$, $p < 0.1$).

A reproducible chronic sleep disorder was reported by 116 persons, and 103 cases were of high severity. Among those affected were five owners of medium-sized companies, as well as some of their company and family members. Due to profoundly diminished performance of the employees and owners alike, the operative existence of these companies is threatened by the impact of the wind turbines. 21 persons moved their bedrooms within their residences, seeking better sleeping conditions. Only minimal improvement was reported. In 53 cases adverse health effects were first experienced after repowering, where smaller wind turbines were replaced with taller ones.

Other complaints and observations
Additional to the chronic sleep disorder, other adverse health effects (Table 2) such as daytime fatigue, difficulty concentrating, performance decline, depression, irritability, anxiety and psychosocial and/or work performance impairment were reported by 127 of the 128 persons suffering from a chronic sleep disturbance. Three credible over-long gestation times of cattle were reported. On livestock farms, reports of stillbirths (calves, lambs), deformation (calves, lambs), other diseases (horses), fertility disorders (cattle, sheep, rabbits) and behavioral problems (cattle, horses, chickens) were reported. Unusual behavior was noticed in dogs and cats. Reports of significant reduction in wildlife sightings (deer, rabbits, large and small birds) were numerous. Many reported that effects related to wind turbine operation were more severe inside than outside their residences. Continually expanding cracks in walls, vibration when placing hands on a wall, and/or watching bedding flatter while lying in bed were also reported.

Discussion

Permissible noise levels in Germany are regulated by the TA-Lärm [7], formulated in 1968 and reformed in 1998. Regulation is based on the sound pressure level with A-frequency weighting that approximates the human hearing sensation, leaving subaudible low-frequency sound and infrasound neither measured nor regulated. The justification for not including infrasound in guidelines for sound protection is that subaudible sound has little or no effect on the human body [13]. However, research indicates that subaudible infrasound does indeed have effects. In 2017 investigators demonstrated that, without conscious perception, subaudible infrasound causes reaction in brain regions known to play a crucial role in emotional and autonomic control [14]. Infrasound also reduces the contractility of isolated human cardiac muscle tissue by 11 to 18%, depending on the loudness [15]. Osteoblast-like cells in vitro are influenced by a 4-20 Hz infrasound exposure of 30 min over five days, as well [16]. Infrasound exposure has been linked to grey matter decline in brain areas associated with somatomotor- and cognitive function [17].

Infrasound generated by wind turbines is detectable up to over 100 km away [18]. A recent study carried out by the Finnish Association for Environmental Health [19] documented no significant decrease in adverse health effects until a residence was 15 km away from wind turbines. Most participants in the present investigation live at distances well below 3 km and all within 10 km of wind farms, so that they are within the influence of infrasound emitted from the wind turbines. Their sleep disorders began in temporal connection with wind turbine operation (wind blowing) or installation of a repowered wind turbine. The sleep disturbances ended recurrently in temporal connection with cessation of the spinning rotor blades (low windspeed, wind-still, wind turbine stopped or withdrawal from wind turbine influence). Despite the bias of this investigation towards interviewing only the severely affected, a relationship between severity of sleep disturbance and distance to nearest wind turbine was apparent, i.e. severity of the sleep disturbance decreased as the distance to the nearest wind turbine increased. Since infrasound levels decrease with distance from their source this indicates that wind turbine generated infrasound could be causal to the observed sleep disturbance.

The attitude towards wind turbines is reported to affect whether adverse health effects are experienced, and a negative attitude is associated with adverse health effects [20]. In the present investigation most participants had either a positive or neutral attitude towards wind energy until they, family members, pets or livestock experienced adverse health effects. Therefore, it is unlikely that attitude played a major role in the occurrence of the adverse health effects reported here.

Neighbors to the same wind turbines often do not experience the same degree of adversity to their health. No definitive explanation for this has been proffered, however, the wide individual range of noise sensitivity in the audible sound range may also apply to sensitivity in the subaudible range. Compared to other noise sources people are much more sensitive to the noise generated by wind turbines. The proportion of people highly annoyed by wind turbine associated noise at 59 dB is approximately 50%, compared to 16% for the same level of aviation associated noise, 13% for industry, 9% for road traffic, and 5% for rail traffic [21], indicating that a noise component emitted during wind turbine operation is not emitted by other sources. Infrasound, differing in quantity or pulsatile quality from non-wind-turbine sources, could be this disturbing component. This hypothesis is supported by the observation that repowering with larger wind turbines, known to generate considerably higher infrasound levels than do smaller wind turbines [2], was often initially associated with the appearance of adverse health effects.

A review based on studies carried out prior to 2009 concluded that infrasound and or vibration from wind turbines could not reach a level to cause adverse health effects in human beings [22]. The height of the towers and length of the rotor blades before 2009 were far less than those for wind turbines that have since been put into operation. Repowering at the time of the present investigation took place with wind turbines approaching 200 m in height. Current installation takes place with wind turbines totaling approximately 250 m in height. In 2012 it was acknowledged that if infrasound couples into structures, inhabitants could feel vibration and that such structural vibration could lead

to feelings of uneasiness and annoyance [23]. However, measurements showed no evidence of coupling from the then modern upwind turbines. In the current investigation reports of expanding cracks in walls, feeling walls vibrate, or watching bedding flatter while lying in bed testify to structure coupling.

Strengths and limitations

The strength of the present study is that it is a first population-based effort towards collecting data concerning wind turbine operation and health in Germany. It is hoped to provide impetus for initiating large-scale epidemiological studies. Limitations to this study are a small sample size and bias towards those persons experiencing pronounced adverse effects to health. A serious limitation is that the infrasonic load of persons with adverse health effects could not be determined. To date measuring infrasonic load is still problematic but the need for further research to establish safety margins regarding infrasound exposure remains undisputed [24]. A study carried out by the German Environmental Agency whereby test persons were exposed short term (30 min) to infrasound emissions, thought to be associated with wind turbine operation, reported no significant physical effects [13]. Epidemiological surveys were deemed necessary to determine whether prolonged infrasound exposure does in fact, as experienced by the participants in this investigation, result in physical effects. However, with no reliable calculation method for determining the experienced infrasonic load, an epidemiological study was considered impracticable.

Outlook

The significance of sleep to health is often undervalued, even though sleep deprivation, depending on duration, leads long term to significant secondary disease [25]. Considering the severity of the sleep disorders far exceeding annoyance encountered during this investigation, we, as concerned physicians, consider epidemiological surveys to be of utmost importance. Studies, however imperfect, due to the inability to presently measure infrasound load, are still indicated to assess health risks associated with wind turbine operation. Efforts to reliably measure infrasound load should be intensified to enable conclusive epidemiological studies.

Conclusions

The chronic, severe sleep disorders related to wind turbine operation encountered in this cohort constitute illness and far exceed tolerable annoyance. Repowering with larger wind turbines, which emit more infrasound than smaller ones, often initiated sleep disorders.

References

1) Krahé D, Schreckenberg D, Ebner F, Eulitz C, Möhler U: Machbarkeitsstudie UBA zu den Wirkungen von Infraschall. Bundesumweltamt 2014 [137 pages]. [cited 2021 May 12] Available from: http://www.umweltbundesamt.de/publikationen/machbarkeitsstudie-zu-wirkungen-von-infraschall
2) Møller H, Pedersen C: Low-frequency noise from large wind turbines. J Acoust Soc Am. 2011; 129(6):3727-44. doi: 10.1121/1.3543957. [cited 2021 May 12] Available from: https://pdfs.semanticscholar.org/5eb3/bf73037fea4bc3fdecd77ace903902c3c285.pdf
3) Empfehlung des Robert Koch-Instituts. Infraschall und tieffrequenter Schall – ein Thema für den umweltbezogenen Gesundheitsschutz in Deutschland? Bundesgesundheitsbl - Gesundheitsforsch -Gesundheitsschutz 2007; 12]. doi 10.1007/s00103-007-0407-3Online. 50; 1582–1589. [cited 2021 May 12] Available from: https://edoc.rki.de/bitstream/handle/176904/290/22wFEQ7q9U2VE.pdf?sequence=1&isAllowed=y
4) Aefis, www.Aefis.de. Positionspapier zu Gesundheitsrisiken beim Ausbau der Erneuerbaren Energien. 2015. [cited 2021 May 12]. Available from: https://aefis.jimdo.com/downloads/
5) Offener Brief zum Thema Infraschall an politisch Verantwortliche. 2019 [cited 2021 May 12]. Available from: http://www.vernunftkraft-hessen.de/wordpress/2019/05/08/offener-brief-an-politisch-verantwortliche-zum-thema-auswirkungen-von-technischem-infraschall-auf-die-gesundheit/
6) Lenzen-Schulte M, Schenk M: Windenergieanlagen und Infraschall: Der Schall, den man nicht hört. Deutsches Ärzteblatt 2019; 116(6) Feb 8. [cited 2021 May 12]. Available from: https://www.aerzteblatt.de/pdf.asp?id=205246
7) German Technical Guidelines to Protect against Noise. [cited 2021 May 12] Available from: https://www.verwaltungsvorschriften-im-internet.de/bsvwvbund_26081998_IG19980826.htm
8) Windradschall-Betroffene -von H.& S. Kaula [cited 2021 May 12] Available from: https://www.youtube.com/channel/UCkoHNBKOoDUQmkHzA0ox86w/videos
9) Onakpoya I, O'Sullivan J, Thompson M, Heneghan C: The effect of wind turbine noise on sleep and quality of life: A systematic review and meta-analysis of observational studies," Environ. Int., vol. 82, pp. 1–9, 2015. Available from: https://docs.wind-watch.org/onakpoya2015.pdf
10) Mayer G, Fietze I, Fischer J, Penzel T, Riemann D, Rodenbeck A, et al.: S3-Leitlinie – Nicht erholsamer Schlaf/Schlafstörungen 2009 [cited 2021 May 12] Available from: https://www.dgsm.de/fileadmin/dgsm/leitlinien/s3/S3-Leitlinie_Nicht_erholsamer_Schlaf-Schlafstoerungen.pdf (p11).
11) Wessa P: (2017), Spearman Rank Correlation (v1.0.3) in Free Statistics Software (v1.2.1), Office for Research Development and Education, URL https://www.wessa.net/rwasp_spearman.wasp/
12) Johannes Gutenberg-Universität Mainz. Chronische Schlafstörungen [cited 2021 May 12] Available from: www.unimedizin-mainz.de/psychosomatik/patienten/psychosomatische-erkrankungen/chronische-schlafstoerungen.html
13) Krahé D, Alaimo Di Loro A, Müller U, Elmenhorst E, De Gioannis R, Schmitt S, et al.: Lärmwirkungen von Infraschallimmissionen - Abschlussbericht 2020. [cited 2021 May 12] [222 pages] Available from: https://www.umweltbundesamt.de/sites/default/files/medien/479/publikationen/texte_163-2020_laermwirkungen_von_infraschallimmissionen_0.pdf
14) Weichenberger M, Bauer M, Kühler R, Hensel J, Forlim CG, Ihlenfeld A, et al.: Altered cortical and subcortical connectivity due to infrasound administered near the hearing threshold - Evidence from fMRI. PLoS One. 2017 Apr 12;12(4): e0174420. doi: 10.1371/journal.pone.0174420.

15) Chaban R, Ghazy A, Georgiade E, Stumpf N, Vahl CF: Negative effect of high-level infrasound on human myocardial contractility: In-vitro controlled experiment. Noise Health [serial online] 2021 [cited 2021 Jul 10]; 23:57-66. Available from: https://www.noiseandhealth.org/text.asp?2021/23/109/57/319800
16) Bing W, Jing-zao C, Zhen-guo G: Effects of infrasonic pressures on the biological features of osteoblast-like cells in vitro. J Low Freq Noise Vibrat Active Control. 2006; 25(3): 215 – 219. [cited 2021 May 12] Available from: https://journals.sagepub.com/doi/pdf/10.1260/026309206779800452
17) Ascone L, Kling C, Wieczorek J, Koch C, Kühn S: A longitudinal, randomized experimental pilot study to investigate the effects of airborne infrasound on human mental health, cognition, and brain structure. Sci Rep **11,** 3190 (2021). https://doi.org/10.1038/s41598-021-82203-6
18) Bowman D: Infraschall d. Stratosphäre belauscht. scinexx 2015 [cited 2021 May 12]. Available from: https://www.scinexx.de/news/geowissen/infraschall-der-stratosphaere-belauscht /?fbclid=IwAR0bANFkcwDw1kKodXgrrPNUOo0SfB3vIGvYq12Irp4ZV12V9RWRwzkZayc

19) Mehtätalo M: The pilot study does not show any significant reduction in damage caused by infrasound until over 15 kilometers from wind farms [cited 2021 May 12] Available from: https://suomenymparistoterveys.files.wordpress.com/2019/01/syte-pilot-study-2016-2.pdf
20) Knopper LD, Ollson CA, McCallum LC, Whitfield Aslund ML, Berger RG, Souweine K, et al.: Wind Turbines and Human Health. Front Public Health. 2014; 2: 63. doi: 10.3389/fpubh.2014.00063
21) Modell zur Gesamtlärmbewertung, concluding report, 2019. (p 76). Available from: https://www.umweltbundesamt.de/sites/default/files/medien/1410/publikationen/2019-06-19_texte_60-2019_modell_zur_gesamtlaermbewertung_abschlussbericht.pdf
22) Colby WD, Dobie R, Leventhall G, Lipscomb DM, McCunney RJ, Seilo MT, et al.: Wind Turbine Sound and Health Effects, An Expert Review Panel. American Wind Energy Association and the Canadian Wind Energy Association. December 2009. [cited 2021 May 12] Available from: http://canada.wpd.de/fileadmin/pdfs/Wind_Turbine_Sound_and_Health_Effects.pdf
23) Ellenbogen JM, Grace S, Heiger-Bernays WJ, Manwell JF, Mills DA, Sullivan KA, et al. Wind Turbine Health Impact Study: Report of Independent Expert Panel. 2012. [cited 2021 May 12] Available from: https://www.mass.gov/files/documents/2016/08/th/turbine-impact-study.pdf
24) Roos W, Vahl C: Infraschall aus technischen Anlagen. Arbeitsmed Sozialmed Umweltmed 2021;56: 420-430.
25) Institute of Medicine (US) Committee on Sleep Medicine and Research; Colten HR, Altevogt BM, editors. Sleep Disorders and Sleep Deprivation: An Unmet Public Health Problem. Washington (DC): National Academies Press (US); 2006. 3, Extent and Health Consequences of Chronic Sleep Loss and Sleep Disorders. Available from: https://www.ncbi.nlm.nih.gov/books/NBK19961/