

MEMORANDUM

VIA EMAIL

TO: Denis Tracy
Whitman County Prosecutor

CC: Alan Thomson
Whitman County Planner

FROM: Nick R. Sweeney, Associate; Erin Anderson, Parter

DATE: July 16, 2025

RE: Role of and information relied upon by planning commission members

I. Introduction

Whitman County is currently considering proposed code amendments that address the siting and permitting of renewable energy resources. The Whitman County Board of Commissioners (“BOCC”) has instructed the planning commission to prepare, for the BOCC’s consideration, proposed amendments to WCC Chapter 19.61 regarding commercial wind energy facilities. This memorandum outlines the planning commission’s role in that process.

Also included here is a short primer on scientific evidence, which may assist the commission’s evaluation of information submitted in support of or in opposition to draft ordinance provisions.

II. Procedural Overview

The Washington Planning Enabling Act, Ch. 36.70 RCW (“PEA”)¹, Whitman County Code (“WCC”) and Washington case law contain standards for a planning commission’s work, including conducting public hearings, and formulating recommendation to the BOCC.

Both the Washington State Constitution, Article XI, Section 11, and the Revised Code of Washington (“RCW”) provide counties the authority to enact ordinances. In Washington state, ordinances are a form of local legislation. In this case, the Whitman County planning

¹ Whitman County is not a county that fully plans under the Growth Management Act, RCW 36.70.

commission members are advisors to the BOCC in their legislative roles. However, the planning commissioners represent the county at large, not particular interests.

Amendments to the WCC are governed by the PEA, which sets minimum procedural standards, and Chapter 19.04 WCC, which mirrors or expands upon the PEA. The commission's role is well defined under both laws: hold a public hearing on the proposed amendments they will recommend to the BOCC. The County must give notice of the public hearing at least ten days prior that specifies the proposed amendment.² The commission shall vote at the conclusion of the public hearing, and submit its recommendation to the BOCC within 14 days.³

III. Standards for Planning Commission Public Hearing and Recommendation

The commission's public hearing and recommendation are not mere procedural checkmarks for code amendments, but critical steps. Thus, the PEA, the WCC and caselaw impose certain standards on their conduct and substance, while affording the commission the wide latitude to engage in the legislative process. "Zoning is a discretionary exercise of police power by a legislative authority" and courts will only disturb that discretion in cases of "arbitrary and capricious conduct" done "without consideration and in disregard of the facts."⁴ The commission's actions must meet this standard to withstand legal challenge.

A. Public Hearing

The commission is required to conduct the public hearing consistent with the "appearance of fairness" doctrine, meaning interested persons have the opportunity to appear and express their views regarding the proposed legislation.⁵ However, the commission's considerations are not limited to public testimony or the materials submitted to them when developing legislation. Planning commissioners "may draw upon all kinds and sources of information including the opinions of experts" and "reach a decision in part from ... personal predilections or preconceptions."⁶ Further, it need only consider and weigh relevant public testimony "in the light of all factors influencing their decision."⁷ Thus, when faced with two opposing opinions or pieces of evidence, the commission can give more weight to the more trustworthy source. Further, the commission need not consider irrelevant or untrustworthy information.

B. Recommendation

The commission must include findings of fact and reasoning for its decision with its recommendation.⁸ It is a best practice and strongly recommended that the findings reference specific evidence supporting the commission's recommendation as well as explain why the

² WCC 19.04.040.B; RCW 36.70.590.

³ RCW 36.70.610.

⁴ *State ex rel. Myhre v. City of Spokane*, 70 Wn.2d 207, 210, 422 P.2d 790 (1967)

⁵ *Smith v. Skagit Cnty.*, 75 Wn.2d 715, 739-40, 453 P.2d 832 (1969), holding modified by *State v. Post*, 118 Wn.2d 596, 826 P.2d 172 (1992)

⁶ *Id.* at 740-41.

⁷ *Id.* at 742.

⁸ RCW 36.70.600; WCC 19.04.060.

commission did not consider irrelevant evidence. Doing so will demonstrate that the commission met its duty to hold a fair public hearing.

IV. Weighing Scientific Evidence

The decision by the BOCC to prepare amendments to the WCC arose out of various wind-related issues being raised by the public. For example, potential public health effects of wind turbines and possible impacts of wind facilities on property values were items raised by county residents when asking that the BOCC revisit WCC 19.61.

In addition to one's own life experiences and knowledge base, all variety of information can inform the basis for legislation, and access to information is nearly unlimited today. Elected and appointed officials writ large (not just the Whitman County planning commission) are presented with news and information in many ways including in person, via the internet, social media, television and radio. Such information ranges from unsubstantiated opinions to studies, reports, books, news articles and myriad other types of information that can speak to positions being weighed in draft or amended ordinances.

With the advent of the internet and the expansive ability to self-publish, the following provides some resources for evaluating information that is presented as scientific evidence. Generally, the scientific method is the systematic approach to acquiring knowledge.⁹ Whether using a five- or a seven-step approach, this is the method of acquiring knowledge through observation, experimentation, and analysis. It involves formulating a hypothesis, testing it through experiments, and drawing conclusions based on the results. How a study is designed is a significant factor in determining its quality and the validity of its results. In the health and medical field "the hierarchy of study design begins with animal [where appropriate] and translational studies and expert opinion, and then ascends to descriptive case reports or case series, followed by analytic observational designs such as cohort studies, then randomized controlled trials, and finally systematic reviews and meta-analyses as the highest qualify evidence."¹⁰ Randomized controlled trials to ascertain the existence of a phenomenon are often referred to as "the gold standard" for research studies to determine causality.¹¹ In other words, study participants should be selected blindly rather than basing studies on individuals who are not selected randomly; otherwise, this introduces the potential for bias in determining the truth of the matter being studied. This can and often includes the existence of a direct causal link between a fact or occurrence and a direct consequence resulting therefrom. To the extent that the Whitman County BOCC or its planning commission find itself presented with competing information including studies purporting to prove conflicting positions, they should give appropriate weight to evidence based on its place in the hierarchy described above.

⁹ See, generally, <https://www.britannica.com/science/scientific-method>.

¹⁰ Wallace SS, Barak G, Truong G, Parker MW. Hierarchy of Evidence Within the Medical Literature. *Hosp Pediatr*. 2022 Aug 1;12(8):745-750 (available [here](#))

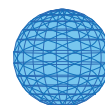
¹¹ Hariton E, Locascio JJ. Randomised controlled trials - the gold standard for effectiveness research. *BJOG*. 2018 Dec;125(13):1716 (available [here](#)).

Likewise, telltale signs of faulty scientific studies the commission should be aware of¹² include:

- Confusing or conflating correlation with causation.
- Conclusions made without evidence.
- Small or unrepresentative samples.
- Lack of control group, blind testing, or peer review.
- Sensationalized headlines
- Misinterpreted results.
- Conflicts of interest.
- Selective reporting of data.
- Results cannot be replicated.

It would be appropriate if a legislator (mayor, BOCC, legislature) discounted evidence that exhibits these flaws, particularly if the evidence also falls out of the hierarchy of research studies described above.

¹² Science Media Center, Desk Guide for Covering Science (available [here](#))



REVIEW

Open Access

Health effects and wind turbines: A review of the literature

Loren D Knopper^{1*} and Christopher A Ollson²

Abstract

Background: Wind power has been harnessed as a source of power around the world. Debate is ongoing with respect to the relationship between reported health effects and wind turbines, specifically in terms of audible and inaudible noise. As a result, minimum setback distances have been established world-wide to reduce or avoid potential complaints from, or potential effects to, people living in proximity to wind turbines. People interested in this debate turn to two sources of information to make informed decisions: scientific peer-reviewed studies published in scientific journals and the popular literature and internet.

Methods: The purpose of this paper is to review the peer-reviewed scientific literature, government agency reports, and the most prominent information found in the popular literature. Combinations of key words were entered into the Thomson Reuters Web of KnowledgeSM and the internet search engine Google. The review was conducted in the spirit of the evaluation process outlined in the Cochrane Handbook for Systematic Reviews of Interventions.

Results: Conclusions of the peer reviewed literature differ in some ways from those in the popular literature. In peer reviewed studies, wind turbine annoyance has been statistically associated with wind turbine noise, but found to be more strongly related to visual impact, attitude to wind turbines and sensitivity to noise. To date, no peer reviewed articles demonstrate a direct causal link between people living in proximity to modern wind turbines, the noise they emit and resulting physiological health effects. If anything, reported health effects are likely attributed to a number of environmental stressors that result in an annoyed/stressed state in a segment of the population. In the popular literature, self-reported health outcomes are related to distance from turbines and the claim is made that infrasound is the causative factor for the reported effects, even though sound pressure levels are not measured.

Conclusions: What both types of studies have in common is the conclusion that wind turbines can be a source of annoyance for some people. The difference between both types is the reason for annoyance. While it is acknowledged that noise from wind turbines can be annoying to some and associated with some reported health effects (e.g., sleep disturbance), especially when found at sound pressure levels greater than 40 db(A), given that annoyance appears to be more strongly related to visual cues and attitude than to noise itself, self reported health effects of people living near wind turbines are more likely attributed to physical manifestation from an annoyed state than from wind turbines themselves. In other words, it appears that it is the change in the environment that is associated with reported health effects and not a turbine-specific variable like audible noise or infrasound. Regardless of its cause, a certain level of annoyance in a population can be expected (as with any number of projects that change the local environment) and the acceptable level is a policy decision to be made by elected officials and their government representatives where the benefits of wind power are weighted against their cons. Assessing the effects of wind turbines on human health is an emerging field and conducting further research into the effects of wind turbines (and environmental changes) on human health, emotional and physical, is warranted.

Keywords: Wind turbines, health, annoyance, infrasound, sound pressure level, noise

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Background

Wind power has been identified as a clean renewable energy source that does not contribute to global warming and is without known emissions or harmful wastes [1]. Studies on public attitudes in Europe and Canada show strong support for the implementation of wind power [2]. Indeed, wind power has become an integrated part of provincial energy strategies across Canada; in Ontario, the Ontario Power Authority has placed a great deal of emphasis on procuring what they term “renewable and cleaner sources of electricity”, such as wind [3].

Although wind power has been harnessed as a source of electricity for several decades around the world, its widespread use as a significant source of energy in Ontario is relatively recent. As with the introduction of any new technology, concerns have been raised that wind power projects could lead to impacts on human health. These concerns are related to two primary issues: wind turbine design and infrastructure (i.e., electromagnetic frequencies from transmission lines, shadow flicker from rotor blades, ice throw from rotor blades and structural failure) and wind turbine noise (i.e., levels of audible noise [including low frequency noise] and infrasound). If left unchecked and unmanaged, it is possible that individually or cumulatively, these issues could lead to potential health impacts. In terms of noise, high sound pressure levels (loudness) of audible noise and infrasound have been associated with learning, sleep and cognitive disruptions as well as stress and anxiety [4-8].

As a result, minimum setback distances have been established world-wide to reduce or avoid potential effects for people living in proximity to wind turbines. Under the Ontario Renewable Energy Approval (REA) Regulation (O. Reg. 359/09, as amended by O. Reg. 521/10), a minimum setback distance of 550 m must exist between the centre of the base of the wind turbine and the nearest noise receptor (e.g., a building or campground). This minimum setback distance was developed through noise modeling under worst-case conditions to give a conservative estimate of the required distance to attain a sound level of 40 dB(A) [9], the noise level that corresponds to the WHO (Europe) night-noise guideline, a health-based limit value “necessary to protect the public, including most of the vulnerable groups such as children, the chronically ill and the elderly, from the adverse health effects of night noise” [8]. Globally, rural residential noise limits are generally set at 35 to 55 dB(A) [10].

This paper focuses on the research involving land-based wind turbine projects. There are several international off-shore marine projects that are in operation. There was considerable interest in Ontario in developing off-shore wind projects on the Great Lakes. However, in February, 2011 the Province announced that it

would not proceed with proposed offshore wind projects until further scientific research is conducted <http://www.news.ontario.ca/ene/en/2011/02/ontario-rules-out-off-shore-wind-projects.html>. This does not appear to have been related, however, to health concerns.

Regardless, debate is ongoing with respect to the relationship between reported health effects and wind turbines, specifically in terms of audible and inaudible noise. People interested in this debate tend to turn to two sources of information in order to make decisions: scientific peer-reviewed studies published in scientific journals, and the popular literature and internet. For the general public, the latter sources are the most readily available and numerous websites have been constructed by individuals or groups to support or oppose the development of wind farms. Often these websites state the perceived impacts on, or benefits to, human health to support the position of the individual or group. The majority of information posted on these websites cannot be traced back to a scientific peer-reviewed source and is typically anecdotal in nature. This serves to spread misconceptions about the potential impacts of wind energy on human health making it difficult for the general public (and scientists) to ascertain which claims can be substantiated by scientific evidence.

Accordingly, the purpose of this paper is to provide results of a review of the peer-reviewed scientific literature and the most prominent information found in the popular literature. We have selected this journal as the source of publication because it is a scientifically credible journal with peer-reviewed articles that are easily accessible by the general population who are interested in the subject of wind turbines and health effects. Results of this review are used to draw conclusions about wind turbines and health effects using a weight-of-evidence approach.

Methods

Peer-Reviewed Literature

Publication of scientific findings is the basis of scientific discourse, communication and debate. The peer review process is considered a fundamental tenet of quality control in scientific publishing. Once a research paper has been submitted to a journal for publication it is reviewed by external independent experts in the field. The experts review the validity, reliability and importance of the results and recommend that the manuscript be accepted, revised or rejected. This process, though not perfect, ensures that the methods employed and the findings of the research receive a high level of scrutiny, such that an independent researcher could repeat the experiment or calculation of results, prior to their publication. This process seeks to ensure that the published research is of a high standard of quality, accurate, can

be reproduced and demonstrates academic/professional integrity.

In order to assess peer-reviewed studies designed to test hypotheses about the association between potential health effects in humans and wind turbines, a review of the primary scientific literature was conducted. While our review did not strictly follow the evaluation process outlined in the Cochrane Handbook for Systematic Reviews of Interventions [11], the standard for conducting information reviews in healthcare and pharmaceutical industries, it was conducted in the spirit of the Cochrane systematic review in that it was designed based on the principle that "science is cumulative", and by considering all available evidence, decisions could be made that reflect the best science available. It also involves critical review and critique of the published literature and at times weighting some manuscripts over others in the same scientific field.

To facilitate this review, combinations of key words (i.e., annoyance, noise, environmental change, sleep disturbance, epilepsy, stress, health effect(s), wind farm(s), infrasound, wind turbines(s), low frequency noise, wind turbine syndrome, neighborhood change) were selected and entered into the Thomson Reuters (formerly ISI) Web of KnowledgeSM. The Web of KnowledgeSM is a database that covers over 10,000 high-impact journals in the sciences, social sciences, and arts and humanities, as well as international proceedings coverage for over 120,000 conferences. The Web of KnowledgeSM comprises seven citation databases, two of which are relevant to the search: the Science Citation Index Expanded (SCI-Expanded) and the Social Sciences Citation Index (SSCI). The SCI-Expanded includes over 6,650 major journals across 150 scientific disciplines and includes all cited references captured from indexed articles. Coverage of the literature spans the year 1900 to the present. On average, 19,000 new records per week are added to the SCI-Expanded. SSCI is a multidisciplinary index of the social sciences literature. SSCI includes over 1,950 journals across 50 social sciences disciplines from the year 1956 to the present. It averages 2,900 new records per week. Use of this literature search platform means the most up-to-date multidisciplinary studies published and peer-reviewed could be obtained.

Although hundreds of articles were found during the search, very few were related to the association between potential health effects and wind turbines. For example, numerous articles have been published about infrasound, but very few have been published about infrasound and wind turbines. Indeed, only fifteen articles, published between 2003 and 2011, were found relevant [12-26]. What can be seen from these articles is that the relationship between wind turbines and human responses to them is extremely complex and influenced by numerous

variables, the majority of which are nonphysical. What is clear is that some people living near wind turbines experience annoyance due to wind turbines, and visual impact tends to be a stronger predictor of noise annoyance than wind turbine noise itself. Swishing, whistling, resounding and pulsating/throbbing are sound characteristics most highly correlated with annoyance by wind turbine noise for those people who noticed the noise outside their dwellings. Some people are also disturbed in their sleep by wind turbines. In general, five key points have come out of these peer-reviewed studies with regards to health and wind turbines.

1. People tend to notice sound from wind turbines almost linearly with increasing sound pressure level

In the studies designed to evaluate the interrelationships amongst annoyance and wind turbine noise, as well as the influence of subjective variables such as attitude and noise sensitivity, Pedersen and Persson Waye [13-15] showed that people tend to notice sound from wind turbines almost linearly with increasing sound pressure level. Briefly, Pedersen and Persson Waye conducted cross-sectional studies (in 2004: $n = 351$; in 2007: $n = 754$) and gave people questionnaires regarding housing and satisfaction with the living environment, including questions about degree of annoyance experienced outdoors and indoors and sensitivity to environmental factors, wind turbines (noise, shadows, and disturbances), respondents' level of perception and annoyance, and verbal descriptors of sound and perceptual characteristics. The third section had questions about chronic health (e.g., diabetes, tinnitus, cardiovascular diseases), general wellbeing (e.g., headache, undue tiredness feeling tensed/stressed, irritable) and normal sleep habits (e.g., quality of sleep, whether or not sleep was disturbed by any noise source). The last section comprised questions on employment and working hours. Of import, the purpose of the study was masked in the questionnaires, which was done to reduce the potential for survey bias.

Of the 754 respondents involved in the Pedersen and Persson Waye study [14], 307 (39%) noticed sound from wind turbines outside their dwelling (range of sound pressure level: < 32.5, 32.5-35.0, 35.0-37.5, 37.5-40.0, and > 40.0 dB(A)) and the proportion of respondents who noticed sound increased almost linearly with increasing noise. In the 37.5-40.0 dB(A) range, 76% of the 71 respondents reported that they noticed sound from the wind turbines; 90% of respondents ($n = 18$) in the > 40.0 dB(A) category noticed sound from the wind turbines. The odds of noticing sound increased by 30% for each increase in dB(A) category. When data from both studies [13,14] were combined ($n = 1095$) results were the same: the proportion of respondents who noticed sound from wind turbines showed increased almost linearly with increasing

sound pressure level from roughly 5-15% of people noticing noise at 29 dB(A) to 45-90% noticing noise at 41 dB(A)[15].

In 2011 Pedersen [25] reported on the results of three cross-sectional studies conducted in two areas of Sweden (a flat rural landscape ($n = 351$) and suburban sites with hilly terrain ($n = 754$) and one location in the Netherlands (flat landscape but with different degrees of road traffic intensity ($n = 725$)) designed assess the relationship between wind turbine noise and possible adverse health effects. Questionnaires were mailed to people in the three areas to obtain information about annoyance and health effects in response to wind turbines noise. Pedersen included questions about several potential environmental stressors and did not allow participants to know that the focus of the study was on wind turbine noise, again in an attempt to reduce self-reporting survey bias. For each respondent, sound pressure levels (dB(A)) were calculated for nearby wind turbines. The questionnaires were designed to obtain information about people's response to noise (i.e., annoyance), diseases or symptoms of impaired health (i.e., chronic disease, diabetes, high blood pressure, cardiovascular disease, tinnitus, impaired hearing), stress symptoms (i.e., headache, undue tiredness, feeling tense or stressed, feeling irritable), and disturbed sleep (i.e., interruption of the sleep by any noise source). Results showed that the frequency of those annoyed with wind turbines was related to an increase in sound pressure level as shown by odds ratios (OR) with 95% confidence intervals (CI) greater than 1.0. Sleep interruption was associated with sound level in two of the three studies (the areas with flat terrain), but unlike the finding that people tend to notice sound from wind turbines almost linearly with increasing sound pressure level, sleep disturbance did not increase gradually with noise levels, but spiked at 40 dBA and 45 dBA.

2. A proportion of people that notice sound from wind turbines find it annoying

Results of the Pedersen and Persson Waye studies [13-15] also suggested that the proportion of participants who were fairly annoyed or very annoyed remained quite level through the 29-37 dB(A) range (no more than roughly 5%) but increased at noise levels above 37 dB(A), with peaks at 38 dB(A) and 41 dB(A), where up to 30% of people were very annoyed. Respondents in the cross-sectional studies (and other studies [12]) noted that swishing, whistling, resounding and pulsating/throbbing were the sound characteristics that were most highly correlated with annoyance by wind turbine noise among respondents who noticed the noise outside their dwellings. This was also found by Leventhall [16]. Seven percent of respondents ($n = 25$) from the Pedersen and Persson Waye study [13] were annoyed by noise from wind turbines indoors, and

this was related to noise category; 23% ($n = 80$) were disturbed in their sleep by noise. Of the 128 respondents living at sound exposure above 35.0 dB(A), 16% ($n = 20$) stated that they were disturbed in their sleep by wind turbine noise. The authors comment that some people may find wind turbine noise more annoying than that of other types of noise (e.g., airplane and traffic) experienced at similar decibel levels.

Similar results were shown by Pedersen and Persson Waye [14]: a total of 31 of the 754 respondents said they were annoyed by wind turbine noise. In the < 32.5 to the 37.5 dB(A) category 3% to 4% of people said they were annoyed by wind turbine noise; in the 37.5-40.0 dB(A) category, 6% of the 71 respondents were annoyed; and in the > 40.0 category, 15% of 20 of respondents said they were annoyed by wind turbine noise. In addition, 36% of those 31 respondents who were annoyed by wind turbine noise reported that their sleep was disturbed by a noise source. Nine percent of those 733 respondents not annoyed said their sleep was disturbed by a noise source. Results of Pedersen [25] showed similar results: the frequency of those annoyed was related to an increase in sound pressure level. Moreover, self reported health effects like feeling tense, stressed, and irritable, were associated with noise annoyance and not to noise itself (OR and 95% CI > 1.0). Sleep interruption, however, was associated with sound level and annoyance (OR and 95%CI > 1.0). Pedersen notes that this finding is not necessarily evidence of a causal relationship between wind turbine noise and stress but may be explained by cognitive stress theory whereby "an individual appraises an environmental stressor, such as noise, as beneficial or not, and behaves accordingly". In other words, it appears that it is the change in the environment that is associated with the self-reported health effects, not the presence of wind turbines themselves.

Keith et al. [17] proposed that in a quiet rural setting, the predicted sound level from wind turbines should not exceed 45 dB(A) at a sensitive receptor location (e.g., residences, hospitals, schools), a value below the World Health Organization guideline for sleep and speech disturbance, moderate annoyance and hearing impairment. The authors [17] suggest this level of noise could be expected to result in a 6.5% increase in the percentage of highly annoyed people. Since publication of the Keith et al. study, the WHO Europe Region has released new Night Noise Guidelines for Europe [8] and state that: "The new limit is an annual average night exposure not exceeding 40 decibels (dB), corresponding to the sound from a quiet street in a residential area". The value of 40 dB is considered the lowest observed adverse effect level (LOAEL) for night noise based on the finding that an average night noise level over a year of 30-40 dB can result in a number of effects on sleep such as body movements, awakening, self-reported sleep disturbance and arousals [8]. The WHO

states that even in the worst cases these effects seem modest [8].

3. Annoyance is not only related to wind turbine noise but also to subjective factors like attitude to visual impact, attitude to wind turbines and sensitivity to noise
Pedersen and Persson Waye [13] revealed that attitude to visual impact, attitude to wind turbines in general, and sensitivity to noise were also related to the way people perceived noise from turbines. For example, 13% of the variance in annoyance from wind farms could be explained by noise and the odds that respondents would be annoyed by noise from wind turbines increased 1.87 times from one sound category to the next. When noise and attitude to visual impact was statistically assessed, 46% of the variance in annoyance from wind farms could be explained and the odds that respondents would be annoyed from wind turbines increased 5.05 times from one sound category to the next. Statistical analyses showed that while attitude to wind turbines in general and sensitivity to noise were also related to annoyance, they did not have a greater influence on annoyance than visual effect. Building on their 2004 paper, Pedersen and Persson Waye [14] conducted a cross-sectional study in seven areas in Sweden across dissimilar terrains and with different degrees of urbanization. Three areas were classified as suburban; four as rural. Noise annoyance related to wind turbines was also statistically related to whether or not people live in suburban or rural areas and landscape (flat vs. hilly/complex). Visual impact has come out as a stronger predictor of noise annoyance than wind turbine noise itself. People who economically benefit from wind turbines had significantly decreased levels of annoyance compared to individuals that received no economic benefit, despite exposure to similar sound levels [18].

One suggestion of the difference between rural and suburban areas is level of background sound and interestingly, perception and annoyance was associated with type of landscape, "indicating that the wind turbine noise interfered with personal expectations in a less urbanised area... pointing towards a personal factor related to the living environment" [14]. The authors also concluded that visual exposure enhances the negative associations with turbines when coupled with audible exposure. They also point out that this study showed that aesthetics play a role in annoyance: "respondents who think of wind turbines as ugly are more likely to appraise them as not belonging to the landscape and therefore feel annoyed" [14].

In 2007 Pedersen et al. [19] conducted a grounded theory study to gain a deeper understanding of how people living near wind turbines perceive and are affected by them. Findings indicated that the relationship between exposure and response is complex and possibly

influenced by variables not yet identified, some of which are nonphysical. The notion that wind turbines are "intruders" is a finding not reported elsewhere. A conclusion of this paper is that when the impacts of wind turbines are assessed, values about the living environment are important to consider as values are firmly rooted within a personality and difficult to change.

In 2008, Pedersen and Larsman [20] conducted a study to assess visibility of wind turbines, visual attitude and vertical visual angle (VVA) in different landscapes. This study follows up on the findings of previous work showing a relationship between noise annoyance in people living near wind turbines and the impact of visual factors as well as an individual's attitude toward noise [13-15,25]. Overall, Pedersen and Larsman concluded that respondents in a landscape where wind turbines could be perceived as contrasting with their surroundings (i.e., flat areas) had a greater probability of noise annoyance than those in hilly areas (where turbines were not as obvious), regardless of sound pressure level, if they thought wind turbines were ugly, unnatural devices that would have a negative impact on the scenery. The enhanced negative response could be linked to aesthetical response, rather than to multi-modal effects of simultaneous auditory and visual stimulation. Moreover, VVA was associated with noise annoyance, especially for respondent who could see at least one wind turbine from their dwelling, if they were living in flat terrain and rural areas. Pedersen and Larsman suggest that these results underscore the importance of visual attitude towards the noise source when exploring response to environmental noise. In 2010 Pedersen et al. [21] hypothesized that if high levels of background sound can reduce annoyance by masking the noise from a wind farm, then turbines could cause less noise annoyance when placed next to motorways instead of quiet agricultural areas. In general, the hypothesis was not supported by the available data [15], further providing support for the notion of visual cue being a strong driver of annoyance.

4. Turbines are designed not to pose a risk of photo-induced epilepsy

Harding et al. [22] and Smedley et al. [23] investigated the relationship between photo-induced seizures (i.e., photosensitive epilepsy) and wind turbine blade flicker (also known as shadow flicker). This is an infrequent event, typically modelled to occur less than 30 hours a year from wind turbine projects we have reviewed and would be most common at dusk and dawn, when the sun is at the horizon. Both studies suggested that flicker from turbines that interrupt or reflect sunlight at frequencies greater than 3 Hz pose a potential risk of inducing photosensitive seizures in 1.7 people per 100,000 of the photosensitive population. For turbines with three blades, this translates

to a maximum speed of rotation of 60 rpm. The normal practice for large wind farms is for frequencies well below this threshold.

Although shadow flicker from wind turbines is unlikely lead to a risk of photo-induced epilepsy there has been little if any study conducted on how it could heighten the annoyance factor of those living in proximity to turbines. It may however be included in the notion of visual cues. In Ontario it has been common practice to attempt to ensure no more than 30 hours of shadow flicker per annum at any one residence.

5. The human ear responds to infrasound

Infrasound is produced by physiological processes like respiration, heartbeat and coughing, as well as man-made sources like air conditioning systems, vehicles, some industrial processes and wind turbines. Salt and Hullar [24] provide data to suggest that the assumption that infrasound presented at an amplitude below what is audible has no influence on the ear is erroneous and summarize the results of previous studies that show a physiological response of the human ear to low frequency noise (LFN) and infrasound. At very low frequencies the outer hair cells (OHC) of the cochlea may be stimulated by sounds in the inaudible range. Salt and Hullar hypothesize that "if infrasound is affecting cells and structures at levels that cannot be heard this leads to the possibility that wind turbine noise could be influencing function or causing unfamiliar sensations". These authors do not test this hypothesis in their paper but suggest the need for further research.

To assess the possibility that the operation of wind turbines may create unacceptable levels of low frequency noise and infrasound, O'Neal et al. [26] conducted a study (commissioned by a wind energy developer, NextEra Energy Resources, LLC) to measure wind turbine noise outside and within nearby residences of turbines. At the Horse Hollow Wind Farm in Taylor and Nolan Counties, Texas, broadband (A-weighted) and one-third octave band data (3.15 hertz to 20,000 hertz bands) were simultaneously collected from General Electric (GE) 1.5sle (1.5 MW) and Siemens SWT-2.3-93 (2.3 MW) wind turbines. Data were collected outdoors and indoors over the course of one week under a variety of operational conditions (it should be noted that wind speeds were low during the measurements; between 3.2 and 4.1 m/s) at two distances from the nearest wind turbines: 305 meters and 457 meters. O'Neal et al. found that the measured low frequency sound and infrasound at both distances (from both turbine types at maximum noise conditions) were less than the standards and criteria published by the cited agencies (e.g., UK DEFRA (Department for Environment, Food, and Rural Affairs); ANSI (American National Standards Institute); Japan Ministry of Environment). The

authors concluded that results of their study suggest that there should be no adverse public health effects from infrasound or low frequency noise at distances greater than 305 meters from the two wind turbine types measured.

Popular Literature

Scientific studies peer reviewed and published in scientific journals are one way of disseminating information about wind turbines and health effects. The general public does not always have access to scientific journals and often get their information, and form opinions, from sources that are less accountable (e.g., the popular literature and internet). Some of the same key words used to obtain references from the primary literature were entered into the common internet search engine Google: "health effects wind farms" returned 300,000 hits; "health effects wind turbines" returned 120,000 hits; "annoyance wind turbines" returned 185,000 hits and "sleep disturbance wind turbines" returned 19,500 hits. What is apparent is that numerous websites have been constructed by individuals or groups to support or oppose the development of wind turbine projects, or media sites reporting on the debate. Often these websites state the perceived impacts on, or benefits to, human health to support the position of the individual or group hosting the website. The majority of information posted on these websites cannot be traced back to a scientific, peer-reviewed source and is typically anecdotal in nature. In some cases, the information contained on and propagated by internet websites and the media is not supported, or is even refuted, by scientific research. This serves to spread misconceptions about the potential impacts of wind energy on human health, which either fuels or diminishes opposition to wind turbine project development.

Works by Dr. Michael Nissenbaum conducted at Mars Hill and Vinalhaven Maine [27] and Dr. Nina Pierpont in New York [28] seem to be the primary popular literature studies referenced on websites. These works suggest a causal link between human health effects and wind turbines. Works by Dr. Robert McMurtry and Carmen Krogh, and Lorrie Gillis, Carmen Krogh and Dr. Nicholas Kouwen [29] have also been used to suggest a relationship between health and turbines. These works have been presented as reports or as slide presentations on websites and authors of these studies have presented their findings in various forums such as invited lectures, affidavits, public meetings and open houses. Briefly, Nissenbaum evaluated 22 exposed adults (defined as living within 3500 ft of an arrangement of 28 1.5 MW wind turbines) and 27 unexposed adults (living about 3 miles away from the nearest turbine). Participants were interviewed and asked a number of questions about their perceived health, levels of

stress and reliance on prescription medications in relation to the turbines [27].

In 2009, a book entitled *Wind Turbine Syndrome: A Report on a Natural Experiment* by Dr. Nina Pierpont, was self-published and describes “Wind Turbine Syndrome”, the clinical name Dr. Pierpont coined for the collection of symptoms reported to her by people residing near wind turbines [28]. The book describes a case series study she conducted involving interviews of 10 families experiencing adverse health effects and who reside near wind turbines. Similar to the process followed by Nissenbaum, people living in proximity wind turbines were interviewed about their health. For all of these works, self-reported symptoms generally included sleep disturbance, headache, tinnitus (ringing in the ears), ear pressure, dizziness, vertigo, nausea, visual blurring, tachycardia (rapid heart rate), irritability, problems with concentration and memory and panic episodes. These symptoms have been purported to be associated with proximity to wind turbines, and specifically, to the infrasound emitted by the turbines. It should be noted that of the 351 people assessed by Pedersen and Persson Waye [13], 26% (91) reported chronic health issues (e.g., diabetes, tinnitus, cardiovascular diseases), but these issues were not statistically associated with noise levels. Results of Pedersen [25] showed similar results: self reported health effects like feeling tense, stressed, and irritable, were associated with noise annoyance and not to noise itself. Sleep interruption, however, was associated with sound level and annoyance.

In 2007, Alves-Pereira and Castelo Branco <http://www.wind-watch.org/documents/industrial-wind-turbines-infrasound-and-vibro-acoustic-disease-vad/> issued a press-release suggesting that their research demonstrated that living in proximity to wind turbines has led to the development of vibro-acoustic disease (VAD) in nearby home-dwellers. It appears that this research has only been presented at a conference, has not been published in a peer-reviewed journal nor has it undergone thorough scientific review. Moreover, Alves-Pereira and Castelo Branco appear to be the primary researchers that have promulgated VAD as a hypothesis for adverse health effects and wind turbines. Indeed, Dr. Pierpont has noted that VAD is not the same “wind turbine syndrome” [28].

To date, these studies have not been subjected to rigorous scientific peer review, and given the venue for their distribution and limited availability of data, it is extremely difficult to assess whether or not the information provided is reliable or valid. What is apparent, however, is that these studies are not necessarily scientifically defensible: they do not contain noise measurements, only measured distances from study participants to the closest turbines; they do not have adequate statistical representation of potential health effects; only limited rationale is provided for the selection of study participants (in some cases

people living in proximity to turbines have been excluded from the study); they suffer from a small number of participants and appear to lack of objectivity as authors are also known advocates who oppose wind turbine developments. Unlike the questionnaires used by Pedersen et al. [13-15,25], the purpose of the studies are not hidden from participants. In fact, the selection process is highly biased towards finding a population who believes they have been affected by turbines. This is not an attempt to discount the self-reported health issues of residents living near wind turbines. Rather, it points out that the self-reported health issues have not been definitively linked to wind turbines.

What the peer reviewed literature and popular literature have in common is the conclusion that wind turbines can be a source of annoyance for some people. Of note are the different reasons and possible causes for annoyance. In the peer reviewed studies, annoyance tends to peak in the > 35 dB(A) range but tends to be more strongly related to subjective factors like visual impact, attitude to wind turbines in general (benign vs. intruders) and sensitivity to noise rather than noise itself from turbines. In the popular literature, health outcomes tend to be more strongly related to distance from turbines and the claim that infrasound is the causative factor. Though sound pressure level in most of the peer reviewed studies was scaled to dB(A) (but refer to O’Neal et al. [26] for actual measurements of low frequency noise and infrasound), infrasound is a component of the sound measurements and was inherently accounted for in the studies.

Annoyance

Studies on the health effects of wind turbines, both published and peer-reviewed and presented in the popular literature, tend to conclude that wind turbines can cause annoyance for some people. A number of governmental health agencies agree that while noise from wind turbines is not loud enough to cause hearing impairment and are not causally related to adverse effects, wind turbines can be a source of annoyance for some people [1,30-34].

It has been hypothesized that the self reported health effects (e.g., sleep disturbance, headache, tinnitus (ringing in the ears), ear pressure, dizziness, vertigo, nausea, visual blurring, tachycardia (rapid heart rate), irritability, problems with concentration and memory, and panic episodes) are related to infrasound emitted from wind turbines [28]. Studies where biological effects were observed due to infrasound exposure were conducted at sound pressure levels (e.g., 145 dB and 165 dB [5,16]; 130 dB [7]) much greater than what is produced by wind turbines (e.g., see O’Neal et al. [26]). Infrasound is not unique to wind turbines but is ubiquitous in the environment due to natural and man-made sources, meaning that people living near wind turbines were exposed to

infrasound prior to turbine operation. For example, Berglund and Hassmen [35] reported that infrasound (a component of low frequency sound) is emitted from road vehicles, aircraft, industrial machinery, artillery and mining explosions, air movement machinery including wind turbines, compressors, and air-conditioning units, and Leventhall [5] reported that infrasound comes from natural sources like meteors, volcanic eruptions and ocean waves. Indeed, many mammals communicate using infrasound [36]. Given the low sound pressure levels of infrasound emitted from wind turbines and the ubiquitous nature of these sounds, the hypothesis that infrasound is a causative agent in health effects does not appear to be supported.

Peer reviewed and scientifically defensible studies suggest that annoyance and health effects are more strongly related to subjective factors like visual impact and attitude to wind turbines rather than to noise itself (both audible and inaudible [i.e., infrasound]). Indeed, many of the self reported health effects are associated with numerous issues, many of which can be attributed to anxiety and annoyance (e.g., Pedersen 2011 [25]). Shargorodsky et al. [37] published that roughly 50 million adults in the United States reported having tinnitus, which is statistically correlated (based on 14,178 participants) to age, racial/ethnic group, hypertension, history of smoking, loud leisure-time, firearm, and occupational noise, hearing impairment and generalized anxiety disorder (based on 2265 participants) identified using a World Health Organization Composite Diagnostic Interview). In fact, the odds of tinnitus being related to anxiety disorder were greatest for any of the variables tested. Folmer and Griest [38], based on a study of 174 patients undergoing treatment for tinnitus at the Oregon Health Sciences University Tinnitus Clinic between 1994 and 1997, reported that insomnia is associated with greater severity of tinnitus. Insomnia is also associated with anxiety and annoyance. Bowling et al. [39] described statistically that people's perceptions of neighbourhood environment can influence health. Perceptions of problems in the area (e.g., noise, crime, air quality, rubbish/litter, traffic, graffiti) were predictive of poorer health score. In their 2003 publication Henningsen and Priebe [40] discussed the characteristics of "New Environmental Illness", illnesses where patients strongly believe their symptoms are caused by environmental factors, even though symptoms are not consistent with empirical evidence and medically unexplained. A key component to such illnesses is the patient's attitude toward the source of the environmental factor. What is more, health effects from annoyance have been shown to be mitigated through behavioural and cognitive behavioural interventions [30,41], lending support to Pedersen's [25] conclusion that health effects can be explained by cognitive stress theory. In other words, it appears that it is the change in the

environment that is associated with health effects, not a turbine-specific variable like infrasound.

Conclusions

Wind power has been harnessed as a source of power around the world. Debate is ongoing with respect to the relationship between reported health effects and wind turbines, specifically in terms of audible and inaudible noise. As a result, minimum setback distances have been established world-wide to reduce or avoid potential effects for people living in proximity to wind turbines. People interested in this debate turn to two sources of information to make informed decisions: scientific peer-reviewed studies published in scientific journals and the popular literature and internet.

We found that conclusions of the peer reviewed literature differ in some ways from the conclusions of the studies published in the popular literature. What both types of studies have in common is the conclusion that wind turbines can be a source of annoyance for some people. In the peer reviewed studies, wind turbine annoyance and some reported health effects (e.g., sleep disturbance) have been statistically associated with wind turbine noise especially when found at sound pressure levels greater than 40 db(A), but found to be more strongly related to subjective factors like visual impact, attitude to wind turbines in general and sensitivity to noise. To date, no peer reviewed scientific journal articles demonstrate a causal link between people living in proximity to modern wind turbines, the noise (audible, low frequency noise, or infrasound) they emit and resulting physiological health effects. In the popular literature, self-reported health outcomes and annoyance are related to distance from turbines and the claim is made that infrasound is the causative factor for the reported effects, even though sound pressure levels are not measured. Infrasound is not unique to wind turbines and the self reported health effects of people living in proximity to wind turbines are not unique to wind turbines. Given that annoyance appears to be more strongly related to visual cues and attitude than to noise itself, self reported health effects of people living near wind turbines are more likely attributed to physical manifestation from an annoyed state than from infrasound. This hypothesis is supported by the peer-reviewed literature pertaining to environmental stressors and health.

The authors have spent countless hours at community public consultation events hosted by proponents announcing new projects and during updates to their environmental assessment process. Historically, citizens' concerns about wind turbine projects appeared to involve potential impact on property values and issues surrounding avian and bat mortality. Increasingly in North America the issue surrounding fears of potential harm to residents' health have come to the forefront of these

meetings. It is clear that the announcement of a new project can lead to a heightened sense of anxiety and annoyance in some members of the public, even prior to construction and operation of a wind turbine project. The authors have been involved in all manner of risk communication, consultation and risk assessment projects in the energy sector in Canada and it has been our experience that this heightened sense of annoyance, agitation or fear is not unique to the wind turbine sector. Whether the proposed project is a wind turbine, gas-fired station, coal plant, nuclear power plant, or energy-from-waste incinerator we have seen a level of concern in a sub-set of the population that goes well beyond anything that would be considered the traditional sense of not-in-my-back-yard (NIMBY). These people genuinely are fearful about the potential health effects that the project may cause, regardless of the outcomes of quantitative assessments that demonstrate that there is a *de minimus* of potential risk in living next to a particular facility. The literature and our own experience highlight the need for informative discussions between wind power developers and community members in order to attempt to reduce the level of apprehension. We encourage continued dialogue between concerned citizens and developers once projects become operational.

Canadian public health agencies subscribe to the World Health Organization definition of health. "*Health is a state of complete physical, mental and social well-being and not merely the absence of infirmity or disease*", a quote often used by both sides of the wind turbine debate. We believe that the primary role of the environmental health/risk assessment practitioner is to ensure that physiological manifestation of infirmity or disease is not predicted to occur from exposure to an environmental contaminant. In terms of wind power, ethics dictate an honest reporting of the issues surrounding annoyance and the fact that it appears that a limited number of people have self-reported health effects that may be attributed to the indirect effects of visual and attitudinal cue. We believe that any physiological based effect can be mitigated through the use of appropriate setback distances. However, it is not clear that for this hypersensitive annoyed population that any setback distance could mitigate the indirect effects. Therefore, it is up to our elected officials and ministerial staff when establishing an energy source hierarchy to weigh all of the information before them to determine the trade-offs between "mental and social well-being" of these individuals against the larger demand for energy and its source.

A number of governmental health agencies agree that while noise from wind turbines is not loud enough to cause hearing impairment and are not causally related to adverse effects, wind turbines can be a source of annoyance for some people. Ultimately it is up to governments to decide the level of acceptable annoyance in

a population that justifies the use of wind power as an alternative energy source.

Assessing the effects of wind turbines on human health is an emerging field, as demonstrated by the limited number of peer-reviewed articles published since 2003. Conducting further research into the effects of wind turbines (and environmental change) on human health, emotional and physical, as well as the effect of public consultation with community groups in reducing pre-construction anxiety, is warranted. Such an undertaking should be initiated prior to public announcement of a project, and could involve baseline community health and attitude surveys, baseline noise and infrasound monitoring, observation and questionnaires administered to public during the siting and assessment process, noise modeling and then post-construction follow-up on all of the aforementioned aspects. Regardless it would be imperative to ensure robust study design and a clear statement of purpose prior to study initiation.

We believe that research of this nature should be undertaken by multi-disciplinary teams involving, for example, acoustical engineers, health scientists, epidemiologists, social scientists and public health physicians. Ideally developers, government agencies, consulting professionals and non-government organizations would form collaborations in attempt to address these issues.

List of Abbreviations

ANSI: American National Standards Institute; CI: Confidence intervals; dB(A): A-weighted decibels; DEFRA: Department for Environment, Food, and Rural Affairs; LFN: low frequency noise; LOAEL: lowest observed adverse effect level; MW: mega watt; O.Reg.: Ontario Regulation; OR: odds ratio; OHC: outer hair cells; REA: Renewable Energy Approval; SCI: Science Citation Index; SSCi: Social Sciences Citation Index; VAD: vibro-acoustic disease; VVA: vertical visual angle; WHO: World Health Organization

Acknowledgements

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Authors' contributions

LDK and CAO both researched and wrote the manuscript. Both authors read and approved the final version.

Competing interests

In terms of competing interests (financial and non-financial), the authors work for a consulting firm and have worked with wind power companies. The authors are actively working in the field of wind turbines and human health. Dr. Ollson has acted as an expert witness for wind power companies during a number of legal hearings. Although we make this disclosure, we wish to reiterate that as independent scientific professionals our views and research are not influenced by these contractual obligations. The authors are environmental health scientists, trained and schooled, in the evaluation of potential risks and health effects of people and the ecosystem through their exposure to environmental issues such as wind turbines.

Received: 2 May 2011 Accepted: 14 September 2011
Published: 14 September 2011

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doi:10.1186/1476-069X-10-78

Cite this article as: Knopper and Ollson: Health effects and wind turbines: A review of the literature. *Environmental Health* 2011 **10**:78.

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The Health Effects of 72 Hours of Simulated Wind Turbine Infrasound: A Double-Blind Randomized Crossover Study in Noise-Sensitive, Healthy Adults

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BACKGROUND: Large electricity-generating wind turbines emit both audible sound and inaudible infrasound at very low frequencies that are outside of the normal human range of hearing. Sufferers of wind turbine syndrome (WTS) have attributed their ill-health and particularly their sleep disturbance to the signature pattern of infrasound. Critics have argued that these symptoms are psychological in origin and are attributable to nocebo effects.

OBJECTIVES: We aimed to test the effects of 72 h of infrasound (1.6–20 Hz at a sound level of ~90 dB pk re 20 µPa, simulating a wind turbine infrasound signature) exposure on human physiology, particularly sleep.

METHODS: We conducted a randomized double-blind triple-arm crossover laboratory-based study of 72 h exposure with a >10-d washout conducted in a noise-insulated sleep laboratory in the style of a studio apartment. The exposures were infrasound (~90 dB pk), sham infrasound (same speakers not generating infrasound), and traffic noise exposure [active control; at a sound pressure level of 40–50 dB LA_{eq,night} and 70 dB LAF_{max} transient maxima, night (2200 to 0700 hours)]. The following physiological and psychological measures and systems were tested for their sensitivity to infrasound: wake after sleep onset (WASO; primary outcome) and other measures of sleep physiology, wake electroencephalography, WTS symptoms, cardiovascular physiology, and neurobehavioral performance.

RESULTS: We randomized 37 noise-sensitive but otherwise healthy adults (18–72 years of age; 51% female) into the study before a COVID19-related public health order forced the study to close. WASO was not affected by infrasound compared with sham infrasound (–1.36 min; 95% CI: –6.60, 3.88, *p* = 0.60) but was worsened by the active control traffic exposure compared with sham by 6.07 min (95% CI: 0.75, 11.39, *p* = 0.02). Infrasound did not worsen any subjective or objective measures used.

DISCUSSION: Our findings did not support the idea that infrasound causes WTS. High level, but inaudible, infrasound did not appear to perturb any physiological or psychological measure tested in these study participants. <https://doi.org/10.1289/EHP10757>

Introduction

Large electricity-generating wind turbines emit both audible sound and inaudible infrasound at very low frequencies that are outside of the normal human range of hearing. There have been several studies published recently on the effects, or lack thereof, of audible wind turbine sound on sleep^{1–4} including a meta-analysis incorporating several of these studies with wake after sleep onset (WASO) as core outcome.⁵ Despite these previous studies generally finding no effect of audible wind turbine noise (WTN) on WASO, other observers^{6–8} have proposed that people

who live in the vicinity of wind turbines suffer from wind turbine syndrome (WTS described in this case series⁹) with dizziness, sleep disturbance, and other symptoms. The causes of this syndrome have been the subject of substantial international controversy.^{10–13} Proponents have contended that the symptoms that compose this syndrome are caused by low frequency subaudible infrasound generated by wind turbines.¹⁴ Critics have argued that these symptoms are psychological in origin and are attributable to nocebo effects.^{9,15–18} The Australian National Health and Medical Research Council (NHMRC) Wind Farms and Human Health Reference Group concluded that the available evidence was not sufficient to establish which, if either, of these explanations is correct.¹⁰ One of the reasons for this is because there had been to our knowledge no robustly designed, double-blind, controlled, and adequately powered studies of the health effects of exposure to sustained infrasound of the type emitted by a wind turbine. This absence of evidence has the potential to complicate initiatives to decarbonize electricity generation due to community concerns about the possibility for this measurable, but inaudible, infrasound to affect their health.

Our principal hypothesis was that exposure to infrasound in healthy individuals, at a level of ~90 dB pk re 20 µPa compared with the sham infrasound, increases WASO—a measure of sleep disturbance—and worsens other measures of sleep quality, mood, WTS symptoms, and other electrophysiological measures. In addition, as a positive control, we also tested whether audible traffic noise, a mixture of road (motorbike, truck, car) and aircraft noise (at a sound level of 40–50 dB LA_{eq,night} and 70 dB LAF_{max} transient maxima) had an adverse impact on these same outcomes, when compared with sham infrasound.

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Supplemental Material is available online (<https://doi.org/10.1289/EHP10757>).

All of the authors have superannuation accounts which are compulsory in Australia and these accounts may contain investments in both traditional and renewable energy, including wind turbines. R.T. is the founding principal of Renzo Tonin Associates who have previously worked as consultants for the NSW Department of Planning on several wind farms in NSW, Australia. None of the investigators have any other pecuniary interest or academic conflicts of interest in the outcomes of this study.

Received 8 December 2021; Revised 9 February 2023; Accepted 21 February 2023; Published 22 March 2023.

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Methods

Study Design, Setting, and Ethics

This was a randomized, double-blind, three-way crossover study (equal ratios of all possible sequences) in noise-sensitive participants exposed during three noncontiguous 72-h periods to *a*) wind turbine simulated infrasound at ~ 90 dB peak, with reference to 20 μPa in air (test exposure); *b*) no added sound (sham, negative control, speakers not generating infrasound); and *c*) traffic noise [positive control mixture of road and air traffic with background levels of 40–50 dB LA_{eq} , at night (2200–0700 hours) and 70 dB LAF_{max} transient maxima]. The metrics LA_{eq} and LAF_{max} are common measures used to indicate the noise level of traffic noise but are not applicable to infrasound, which has a frequency range of <20 Hz. Although any number of metrics could be used to measure the amplitude of infrasound, in this study the use of dB pk is adopted, corresponding to the peak amplitude of the infrasound waveform, to enable comparison with the dB pk level measured at a working wind farm, as described in more detail in the section “Experimental Exposures (Infrasound, Sham, and Traffic).”

The study was conducted exclusively at the Woolcock Institute of Medical Research, Glebe, New South Wales, Australia, in our sleep laboratory which is shielded from external sound. The ambient underlying noise level in the sleep laboratory in the nighttime period (i.e., without the generated traffic noise) was ~ 39 dB $\text{LA}_{\text{eq,night}}$ with the air-conditioning operating in the room. Air-conditioning was not turned off during the experiment to prevent ambient elevated temperature disturbing sleep. The ambient underlying level of infrasound was 80–85 dB pk predominantly in the frequencies of <1 Hz (i.e., below the frequency range of the simulated infrasound).

During each test period starting around noon, the participants were subjected to one of the three noise conditions continuously for 72 h (including 3 normal nocturnal sleep periods) without leaving the testing setting (bedroom with ensuite approximating a studio apartment). The testing protocol within each 72-h period is described in Figure S1. Each noise condition was separated by a >10 -d washout period during which participants lived normally outside of the laboratory environment.

This study was registered in the Australian and New Zealand Clinical Trials Registry (ACTRN12617000001392) before the first participant was randomized. A full copy of the final study protocol followed throughout the study without amendment and was lodged in the registry before the first participant was randomized after it was approved by the Sydney Local Health District Ethics Committee at The Royal Prince Alfred Hospital (protocol nos. X16-0073 and HREC/16/RPAH/91) and was performed in accordance with the Declaration of Helsinki, the 2006 *Australian Clinical Trials Handbook Version 1.0*, and the guidelines of the NHMRC for human research.¹⁹ Participants also gave written informed consent. Participants were offered an AUD1,000 payment upon completion ($\sim$ AUD4.55/h in the laboratory) and the study paid for all transportation and meal costs.

Randomization Sequence, Allocation Concealment, and Blinding

The randomization sequence was a simple 1:1:1 ratio with no blocking that was computer generated by an investigator (C.T.C.) who played no role in participant selection or data collection and never met any participants or undertook statistical analysis. The sequence was secured in our password-protected research database and was only accessible by that investigator and the acoustic and data engineers who played no role in the screening for

eligibility or the decision to randomize participants. The principal investigator (PI) and lead study coordinator assessed eligibility and consent before the PI irrevocably recorded the decision to randomize against the participants' screening number and this was recorded by the study database.

Participants and study staff were blinded to the infrasound and sham infrasound exposures (given that the infrasound is inaudible). Study investigators and outcome assessors/processors were blinded to study allocation by using engineering staff who were solely responsible for delivering the exposures based on the randomization schedule and who never disclosed to any other study staff what exposure had been used, would be used, or was occurring. Infrasound or sham generation were controlled from a locked box kept outside the participants' room only accessible by the engineers. Engineering staff did not meet the participants. The audible positive control (loud traffic noise) by its nature cannot be subject to either participant or investigator blinding and was an open-label exposure.

We asked all of the participants and staff during our informal conversations with them whether they could sense that infrasound was playing. None of the participants said they could sense infrasound was playing. None of the staff who processed the electrophysiology measurements [including polysomnography (PSG)] or were in the presence of the participants reported being able to tell whether infrasound or sham infrasound was being delivered. Statistical analyses were undertaken by investigators (N.S.M. and G.C.) who were also unable to tell which condition was infrasound. Exposures were labeled numerically (1 vs. 2 vs. 3) in the database rather than descriptively (traffic vs. infrasound vs. sham) until after the principal analyses were completed and presented to the chief investigators.

Participants

We undertook a two-stage screening process (online and clinical screening). Online screening selected for adults who were fluent in English, ≥ 18 y old, and who were noise sensitive (21-Question Weinstein Noise Sensitivity Scale, with a score above the reported mean for the measurement of >58),²⁰ did not have severe insomnia (7-question Insomnia Severity Index of ≤ 18),²¹ or any other detectable medical or psychiatric morbidity (including caffeine, alcohol, tobacco, or hypnotic dependence) that would preclude residing in a controlled environment for 72 h. We also excluded women who reported being pregnant or breastfeeding owing to the unknown risks to unborn children and babies. To benchmark the sample for mood and sleepiness levels, we also measured the Depression Anxiety and Stress Scale (DASS-21) and the Epworth Sleepiness Scale (ESS).^{22,23} We measured participants' attitudes to windfarms (“How concerned are you about the health effects of infrasound generated from wind farms?”) with a Likert scale (0–6, with 0 being completely unconcerned to 6, extremely concerned); we planned to test this in the context of a main effect of infrasound as a potential explanatory variable (Figure S2).

Online-screened eligible participants were invited to proceed to the clinical screening stage. The clinical screening involved sending participants an Actiwatch 2 (Philips Respironics) using light and movement measurements to determine at-home sleep/wake patterns which were then clinically interpreted by a sleep psychologist (D.J.B.). Instructions were provided on how to use the watch and to wear it for a minimum period of 7 nights. Participants were excluded if that actigraphy recording showed abnormal sleep patterns, such as unusually short/late/early and shift work and/or transmeridian travel within 2 wk preceding randomization. Eligible participants were then invited to attend an in-person screening at the Woolcock Institute of Medical Research for audiological testing, psychological review and, if relevant, sign

informed consent documents. Psychological screening was conducted by a psychologist (D.J.B.) who interviewed participants and reviewed their psychological history and questionnaire data [including assessments of claustrophobia (the Claustrophobia Questionnaire or CLQ)]²⁴ and determined whether they were likely to tolerate 72 h in a studio apartment style accommodation.

Audiological screening was conducted to exclude any participants who had an existing hearing loss. Only those with normal audiometry in the opinion of the audiologist and neurotologist (M.S.W.) were included. As per a standard audiological examination, otoscopy, tympanometry, and pure tone audiometry (PTA) were conducted.

Otoscopy was conducted to check for the presence of excessive wax or anything that could obstruct probe measurements for tympanometry. Tympanometry provides quantitative information on the function of structures and the presence of fluid in the middle ear and was done to exclude those with underlying middle ear pathology that may impact upon sound transmission to the inner ear. Tympanograms were recorded using a Madsen OTOflex 100 (Natus Medical) system with a 226-Hz probe tone.²⁵ Static compliance (in millimho), middle ear pressure (in decapascals) and ear canal volume (in cubic centimeters) were recorded. Only those with clinically normal middle ear function as indicated by equipment norms (static compliance of ≥ 0.3 mmho and middle ear pressure of between -100 and 100 daPa) were included in the study.

PTA was conducted using a personal computer-based audiometer (Oscilla USB-350B; Inmedico A/F), and thresholds were obtained following standard clinical practice using the Hughson-Westlake procedure.²⁶ Thresholds were recorded at 250, 500, 1,000, 2,000, 4,000, and 8,000 Hz for air conduction (AC) and at 500, 1,000, 2,000, and 4,000 Hz for bone conduction (BC); 125 Hz AC thresholds were not tested owing to the risk of vibrotactile stimulation, which could affect the reliability of the results. Only participants with AC and BC thresholds at ≤ 20 dB Hearing Level (HL) (i.e., clinically normal hearing) were included in the study.

Experimental Exposures (Infrasound, Sham, and Traffic)

The infrasound attributable to wind turbines was simulated digitally using a trapezoidal-shaped waveform with 16 harmonics in the frequency range of 0.8–20 Hz at a sound level of ~ 90 dB pk re 20 μ Pa (measurable but inaudible to all participants).¹⁶ This infrasound level is higher than what has been recorded both inside and outside a dwelling where people have previously reported WTS from exposure experienced at 1,100 ft (335 meters) from a wind turbine located at the Shirley Wind Farm, Wisconsin, USA.^{14,27} The Shirley wind project has eight Nordex100 wind turbines. The simulated wind turbine infrasound was generated by a Teensy microprocessor fitted with an SGTL5000 audio processor and the signal fed to a purpose-built Direct Current (DC)-coupled class D amplifier and four 18-in JBL subwoofer loudspeakers in four fully sealed timber enclosures faced with heavy protective mesh so that the participants could not observe the speakers in operation. The simulated wind turbine infrasound comprised sinusoidal harmonics in the frequency range specified with monotonically decreasing amplitude and selected phase shift, resulting in a trapezoidal waveform as observed in field measurements (Figure S3).⁵ The sham infrasound exposure involved use of the same equipment but with the loudspeakers wired in antiphase so that the cones moved by an equivalent amount but did not generate infrasound.

Because of the limitation in the physical size and type of loudspeakers, the 0.8-Hz fundamental frequency could not be generated at the required sound level and so the frequencies

generated commenced at the second harmonic at 1.6 Hz. The peak sound level was nonetheless maintained as specified.

A mixture of road (motorcycles, trucks, cars) and aircraft noise (referred to herein as traffic noise) was generated via a Bose audio sound system and audio digital player at a sound level of 40–50 dB LA_{eq,night} and 70 dB LAF_{max} (loud enough to disrupt normal conversation). The traffic noise was timed specifically to disrupt the last 3 h of sleep as a positive control condition to increase WASO. The six sound files that constituted this exposure are available as supplemental audio files 1–6 upon request to the authors. The counts of sound events labeled airplane, motorbike, truck, or car can be found in Figure S4 for the full 72 h. Traffic noise events occurred approximately three to four times an hour during daylight and early sleep but, between ~ 0400 and 0700 hours, the traffic noise events occurred closer to 15 events an hour (for a person with a normal wake time about 0700 hours). The events in the last 3 h of sleep were clustered noise events occurring one after the other. A typical noise event outside of the time 0400–0700 hours would be experienced as a truck going past. But between the 0400–0700 hours, the experience would be six trucks going past one after the other.

The infrasound sound levels were measured continuously above the pillow of each participant using a GRAS 46AZ one-half inch low frequency microphone and preamplifier set connected to the microprocessor. Software was used to enable the overall dB pk sound level and narrow band frequency analysis to be measured continuously and stored at 1-s intervals for later processing. The sound levels of the traffic noise were measured using an NTi XL2 sound level meter (having a frequency bandwidth of 10 Hz–20 kHz) with its microphone placed adjacent to the infrasound microphone. There was no attempt to address noise from the subjects such as snoring, talking in their sleep, or turning over in bed because it was considered that this extraneous noise would not contribute to the LA_{eq,night}, which is measured over the whole nighttime period. A review of the sound levels was made after each session to identify any unusual extraneous noise. The equipment was calibrated before and after each test period with a Bruel & Kjaer 4231 sound level calibrator to confirm there was no drift in calibration. After the experiment, an acoustic engineer (O.J.) compared the exposure received to the exposure allocated by the randomized sequence to check for correct allocation and also for any equipment malfunction or performance issues.

Neurophysiological Measurements of Sleep and Wake

The primary and secondary outcomes were neurophysiological measurements of sleep and wake. Participants were measured using PSG at three time points per visit (1 sleep study per night). PSG was measured using Alice 6 LDX and Sleepware G3 (Philips Respironics) at electroencephalographic (EEG) derivations (F3-A2, Fz-A2, F4-A1, C3-A2, Cz-A2, C4-A1, Pz-A2, O1-A2, Oz-A2, O2-A1), left and right electrooculogram (EOG), chin electromyogram (EMG), and lead II electrocardiogram (ECG). Additional PSG sensors, such as nasal cannula and thermistor (to measure airflow), thoracic and abdomen respiratory bands, and leg EMG were measured during the first night of each visit. For nights 2 and 3, only EEG, EOG, ECG, and Chin EMG were measured. The PSG was manually scored by a sleep technician blinded to noise conditions (except traffic) according to the American Academy of Sleep Medicine guideline that was operational at the time when the study started (version 2.2).²⁸

To reduce laboratory-induced variability in sleep behavior, individualized habitual sleep and wake times were calculated based on the average sleep and wake times from the 7 d of actigraphy measured during screening. Participants' sleep opportunity

period in the laboratory protocol was calculated using their habitual sleep and wake times with an additional 30-min windows on each end. Participants could then elect a set time inside those 30-min windows to be their go-to-sleep and wake-up times that they would then follow for the duration of the protocol.

Our primary outcome, WASO, was measured in minutes and was calculated from the first epoch of any sleep detected on the polysomnogram until the last epoch of any sleep detected on the PSG or the participant's individually calculated habitual wake-up time, whichever happened last. Sleep technicians and staff were instructed to keep in-room disruption (e.g., fixing signals or physiological sensors) to a minimum to reduce artificially induced wake impacting the WASO calculation. All other PSG outcomes were scored according to the guideline and analyzed in the order in which they were listed in the preregistration.

EEG microstructure (power spectral density and spindle density) was analyzed by importing the PSG as a European data format (EDF) and sleep stage file into an in-house-built program.^{29–31} Preprocessing consisted of manual artifact detection and visual signal quality checks prior to exporting the EDF file. If judged that >25% of the primary EEG channel (Cz-A2) was artifact, we substituted EEG channel (C3-A2). Where both EEG channels were deemed nonvalid, PSG recordings were excluded from analysis. The program calculates power for five frequency bands [beta (β) frequency band = 15–32 Hz; sigma (σ) frequency band = 12–15 Hz; alpha (α) frequency band = 8–12 Hz; theta (θ) frequency band = 4.5–8 Hz; delta (δ) frequency band = 0.5–4.5 Hz] in both rapid eye movement stage (REM) and non-REM sleep. The output of this program provides the “power” describing the density of each predefined EEG frequency bands during the PSG recording. This program also automatically detects the number of sleep spindles per minute during non-REM sleep (11–16 Hz) and fast and slow frequency spindles (fast 14–16 Hz; slow 11–13 Hz). Sleep spindles are a distinctive feature of non-REM sleep that are thought to play a role in memory and sleep stability.

Additional Secondary and Tertiary Outcome Measures

Neurocognitive battery and affective scales. The battery of tests was repeated 12 times per visit and therefore a maximum of 36 times per participant. The exact sequence and timing of the battery are provided in Figure S1 and Table S2.

VAS. Participants were asked to plot on a 100-mm scale/line to indicate the momentary severity of symptoms reported in WTS (see Figure S5 for an example). The distance from the left end of the line to the participants' response was recorded in millimeters. The 19 symptoms measured were: Headaches, Ringing in the ear, Itchy Skin, Blurred Vision, Dizziness, Racing Heart, Nausea, Tiredness, Feeling Faint, Sleepiness, Difficulty Concentrating, Difficulty Remembering, Fatigue, Irritability, Muscle Spasms, Disruption while falling asleep, Awakening from Sleep, and Anxiety. We also measured an additional visual analog scale (VAS) asking how annoying the noise is right now (Figure S5). The statistical processing of the 20 VAS is described in the “Statistical Analyses” section.

Karolinska Drowsiness Test. Participants were asked to look at a dot directly in front of them at eye level (~1 m away) for 2.5 min followed by 2.5 min with eyes closed and, last, another 2.5 min with their eyes opened. EEG was simultaneously measured (Alice Respirationics G3 Sleepware). The alpha density in the eyes-open and the eyes-closed states, as measured in the EEG evaluates the level of wakefulness in participants during the course of the test. EEG data was exported into an EDF that was processed using an in-house analysis program.^{29,30}

N-back. The N-back test is a computerized test which involved the participant monitoring a series of stimuli (letters)

and requires them to respond whenever a stimulus was presented in the same location as the one presented two trials previously. The task requires monitoring, updating, and manipulation of memorized information and is, therefore, assumed to place great demand on a number of key processes within working memory. The total number of correct responses out of 48 trials is the outcome. Before unblinding, we excluded all scores <10 correct as evidence that a participant had not followed instructions.

Tower of London. This is a neuropsychological test of planning, executive/spatial function, and working memory.^{32,33} The participant is instructed to move three colored balls on three pegs from an initial state to a goal state in the minimum number of moves necessary. Each trial contains multiple problems of increasing difficulty, requiring the participant to set more sub-goals to reach the illustrated goal and requires preplanning. Each trial has a prespecified number of moves that the participant must aim to complete the trial within. The variables analyzed in this task are the mean of planning + execution time and the grand mean number of errors across all puzzles attempted.

Psychomotor vigilance task. This test is a measurement of simple reaction time (RT) over a 10-min period using an independent hand-held box with an light emitting diode (LED) display and two buttons that can be depressed using your thumbs. Participants are instructed to respond to a red LED display counting up in milliseconds that is stopped by pressing the right button as fast as possible. Stimulus delivery is randomly spaced between 2 and 10 s after the last one. An overall mean RT over the 10 min of the test period is generated (mean RT) and reciprocated to normalize the distribution.^{34,35}

End-of-visit questionnaire. Participants were asked four computerized questionnaires before exiting the laboratory environment at the end of each visit. These questionnaire, which are described in Table S1 are the Insomnia Severity Index (modified to a 3-day version), Kessler-10, Warwick—Edinburgh Mental Wellbeing Scale, Depression Anxiety Scale, and Stress Scale DASS-21).

Cardiovascular and Blood Measurements

Twenty-four-hour blood pressure. Participants had ambulatory blood pressure measured over a 24-h period each visit using the Oscar2 device (SunTech Medical). Blood pressure measurements were taken at the brachial location, using a blood pressure cuff sized according to each participant's arm. This procedure occurred from the morning of the second day to the third day of each visit. Blood pressure readings occurred at half-hourly intervals while participants were awake and hourly when participants were asleep (50 measurements per visit). Participants were instructed to keep their arm relaxed during readings and were notified there would be two inflations of the cuff (arterial and central blood pressure). Data was recorded and downloaded using provided programs by SunTech Medical and exported into comma-separated files for SAS import and statistical analysis.

Endothelial function test. This procedure was undertaken once per visit at approximately noon after the last night and ~2 h after the completion of noise exposure. In this 15-min test, participants were required to rest in a supine position on a bed while vascular tone was measured at the index fingers of each hand using the EndoPAT device (Itamar Medical). Vascular tone was measured at a baseline resting state at both fingers for 5 min. Following the reading at rest, a blood pressure cuff was inflated for 5 min on one arm to a pressure of 80 mmHg above their resting blood systolic pressure or 200 mmHg, whichever occurred first. A baseline blood pressure measurement was taken prior to the test to determine the pressure of cuff inflation. Following the occlusion period, the blood pressure cuff was fully deflated to allow measurement of

endothelial mediated vasodilation (endothelial function). The cuff then remained deflated for another 5 min of rest.

Blood-based cardiovascular markers. A fasted blood sample was collected on the final morning of each visit. Due to infection and safety procedures surrounding venipuncture, participants were briefly taken away from the noise exposure to perform blood draws in a separate room. Blood samples were commercially processed using standard assays by a local pathology company (Lavery Pathology, Sydney, Australia). Four serum variables were prespecified as of interest and were entered from the pathology reports: cortisol [a potential measure of stress; limit of detection (LOD) was 5.5 nmol/L], highly sensitive C-reactive protein (HsCRP; a measure of inflammation; LOD of 0.1 mg/L), glucose and insulin (measures of metabolic homeostasis that might be perturbed by sleep disruption; the glucose LOD was 0.1 mmol/L and the insulin LOD was 0.2 mU/L). When a value was reported as being below the level of detection for any of these variables, we entered that value as being at that level (except HsCRP). Only HsCRP was ever reported with a lower than detectable level result (see the “Results” section).

Pulse wave velocity. This procedure was undertaken once per visit at ~1000 hours the morning after the second night and while in the presence of the speakers. This 10-min test required participants to be supine on the bed with a baseline rest period of 5 min prior to measurements using the SphygmaCor-XCEL (AtCor medical). A blood pressure cuff was attached around the participants’ thigh, and their carotid pulse was located using a high-fidelity pressure tonometer at the neck on the same side of the body. The carotid and femoral pulse waves were then simultaneously acquired from the thigh cuff and the tonometer. Pulse wave velocity was calculated based upon the distance between the middle of the thigh cuff and the site of the carotid pulse using established techniques.³⁶ Recordings were deemed technically acceptable if pulse waves could be simultaneously acquired for at least 10 s.

Twenty-four-hour urinary catecholamines. On the morning of the third day, participants were provided with a 24-h urine collection container and asked to void their bladder immediately prior to urine collection commencement. All urinary output was then collected in the container until the following morning. Urinary catecholamines were commercially processed using standard assays used by a local pathology company (Lavery Pathology, Sydney, Australia). The pathology service assayed these urine samples for creatinine, noradrenaline, adrenaline, and dopamine. Noradrenaline, adrenaline, and dopamine levels were divided by the amount of creatinine for statistical analyses. The minimum levels of detectable noradrenaline and adrenaline values are ~14.0 nmol/L, creatinine is detectable at 2 mmol/L, and dopamine is detectable above levels of ~200 nmol/L. Values at the LOD indicated in the pathology report were entered in as being at that point (e.g., <38 nmol/24 h of adrenaline was data entered as 38).

Statistical Analyses

In our prestudy planning, we calculated that in a crossover study design, a sample size of 38 participants would provide ~85% power to detect a difference in the primary end point, WASO, of 15 min between infrasound and sham infrasound (Cohen’s $d=0.5$). Our analysis code is available in the University of Sydney’s data repository and can be accessed on request of the authors. Repeated linear mixed models were performed for the primary and secondary end points in SAS (version 9.4; SAS Institute, Inc.), including all randomized participants in the groups they were randomized to and using the least squares means procedure to address missing data. For the primary and secondary outcomes, Participant Identification Numbers were

coded as random effects, and we used the exposure received, the order it was received, the night of exposure and interactions between the exposure by night, and night by order as fixed effects. We regarded $p < 0.05$ as statistically significant, and exposure effects were tested using the least squares means option. Tertiary outcomes were analyzed using the same model without the night effect or any of its interactions but, instead, included a time-point term indicating how far through the sequence the test was made. Blood pressure had 50 repeated measurements per visit and the repeated daytime test battery data, including symptom VAS scores, had 12 repeated measurements per visit.

Because a large proportion of VAS scores were 0/100 and to reduce the number of end points, a post hoc decision was made to use principal components factor analysis (proc factor). We used squared multiple correlations of each variable with the 19 other variables (including the noise annoyance scale) as the prior communality estimates. We selected five factors to be extracted based on an examination of the scree plot and evaluation of the interpretability of the resultant rotated factors. Varimax orthogonal rotation was implemented after extraction. The five factors were labeled according to the variables that loaded on them, as follows: Fatigue, Irritability, Nausea and Dizziness, Sleep Disturbance, and Tinnitus. Scores for each factor for each subject on each of 36 occasions of measurement were calculated. These factor scores had 3 added to them and then were log-transformed to approximate a normal distribution. The log-transformed factor scores were used as dependent variables in five mixed effects regression models.

Results

Between 19 April 2017 and 23 March 2020, we randomized 37 participants (see Table 1 for demographic information), 2 of whom withdrew themselves from the study after one exposure (see the “Adverse Events” section) and 1 of whom completed infrasound and sham infrasound exposures, but not the positive control exposure because our facility was closed by a COVID-related public health directive (5 missed exposure visits in total). Within conditions data collection was interrupted for 2 participants on night 1 (power cut) and night 2 (a staff scheduling error) that meant we had to send those participants home for 1 night.

The lead authors (N.S.M. and G.C.) asked all of the staff and all of the participants whether they were able to differentiate in any way between infrasound and sham infrasound. None of them were able to. The sound engineer checked whether participants were exposed to the condition that they were scheduled to be exposed to in the randomization sequence. For one participant, the first and third visit, traffic and infrasound respectively were inadvertently switched compared with the randomization schedule due to human error. All randomized participants were analyzed for primary and secondary outcomes. Analysis was by intention-to-treat, that is, according to the randomly assigned exposure condition. The model estimated effects of infrasound and traffic noise compared with sham infrasound for all outcomes are shown in Table 2. Because there was no main effect of infrasound on sleep, we did not test for an interaction with prestudy attitudes to the health effects of windfarms. Five of 62 outcomes listed in Table 2 were found to be significantly different in the infrasound exposure (8.1% compared with the false positive rate of 5%): blood pressure [−2.1 mmHg; 95% confidence interval (CI): −2.9, −1.2]; insulin (−1.7 mU/L; 95% CI: −3.3, −0.2); percentage REM (% REM) sleep (1.5%; 95% CI: 0.3, 2.7); Warwick–Edinburgh Mental Wellbeing Scale (1.9 points; 95% CI: 0.2, 3.5); and change in power in the alpha frequency in the eyes-closed condition (−2.00 μV^2 ; 95% CI: −3.95, −0.04). Figure 1 shows the estimated effect of infrasound, sham infrasound, and

Table 1. Participant demographics in the laboratory-based three-arm cross-over study of 72 h of exposure to simulated wind turbine infrasound, sham infrasound, and traffic noise.

Variable	Descriptive statistics	Range
Sex, <i>n</i>		
Females	19	
Males	18	
Age [y (mean ± SD)]	32 ± 12	18–72
Weinstein Noise Sensitivity Score (0–126 points) (mean ± SD)	83.0 ± 13.4	64–108
Insomnia Severity Scale (0–28 points) (mean ± SD)	5.3 ± 4.4	0–16
DASS-21 ²³ —Depression (0–21 points) (mean ± SD)	3.7 ± 4.3	0–16
DASS-21 ²³ —Anxiety (0–21 points) (mean ± SD)	2.5 ± 3.5	0–12
Epworth Sleepiness Scale (0–24 points) (mean ± SD)	4.7 ± 3.4	0–13
Attitude toward windfarm (0–6) [median]	3	0–6, including 7 participants with scores >3

Note: There were no data missing for any of these variables; baseline data was complete in all participants. Weinstein scores had to be >58 to be eligible (approximately the median value in community-dwelling people, rather than a cutoff value indicative of a person being noise sensitive) and an Insomnia Severity Index (ISI) of ≤18. ISI scores <8 indicate no insomnia; <15, subthreshold insomnia; and <22, moderate severity insomnia. Participants had to be at least 18 years of age. No other metrics reported were subject to inclusion/exclusion for a participant to be eligible. Scores <10 on the DASS Depression scale indicate no depression, scores between 10 and 13 indicate mild depression, and scores between 14 and 20 indicate moderate depression. Scores <8 on the DASS Anxiety scale indicate no anxiety, scores between 8 and 9 mild anxiety, and scores between 10 and 14 moderate anxiety. Scores >10 on the Epworth Sleepiness Scale indicate clinically significant daytime sleepiness, and scores >16 severe daytime sleepiness (see the “Participants” section in the “Methods” section for more detail). Attitude toward windfarm was scored from 0 (completely unconcerned) to 6 (extremely concerned). DASS, Depression Anxiety and Stress Scale; SD, standard deviation.

traffic noise on the primary outcome (WASO) after 3 nights of each exposure, indicating the lack of effect of infrasound on WASO compared with sham and the effect of traffic noise on the first 2 nights. There was no evidence of a first-night effect whereby participants’ WASO were worse on the first night they spent in the laboratory ($p = 0.63$). Figure 2 shows the estimated effects on other standard electrophysiological measures of human sleep quality, including sleep onset latency (Figure 2A), sleep stage shifts (Figure 2B), the arousal index (Figure 2C), and the distribution of the five sleep stages (Wake, N1, N2, N3, and REM; Figure 2D) for each of the three exposures. Figure 3 shows the quantitative analysis of the EEG at Cz (top middle of the scalp) in the five frequency bands during sleep (delta, theta, alpha, sigma, beta) for each exposure in non-REM sleep (Figure 3A), REM sleep (Figure 3B), and the sleep spindle analysis (Figure 3C), again showing the lack of perturbed human sleep quality/continuity that could be attributable to infrasound.

Adverse Events

There were no serious adverse events (unplanned hospitalizations or deaths). There were four adverse events in participants, who we describe in this section as participants A, B, C, and D. Participant A completed only one visit while being exposed to infrasound. They complained that the tips of their hair were being made brittle by the EEG paste and declined further contact and participation. We found no pattern of complaints in their data that would match WTS after reviewing all their objective and subjective data after unblinding. Participant B completed only one visit while being exposed to sham infrasound. They complained of social isolation and did not enjoy being in a windowless room and then declined further contact and participation. Participant C

completed all visits and during the first visit was exposed to traffic noise and had a mild asthma attack possibly triggered by a bushfire event in Sydney that weekend. This participant was immediately seen by a respiratory physician in our clinic to update their asthma management before they left the laboratory. Participant D completed all visits but emailed the study coordinator to report feeling on edge in the immediate days after returning home from the second visit (infrasound exposure). We then reviewed their data where they did not report having, or later retrospectively report having, that experience in the laboratory environment.

Data Quality

Our quality assurance for our blood pressure/heart rate data indicated that other than the missing data at a participant level (where 2 visits were missed because of equipment availability and a staff scheduling accident plus the 5 missed visits from people dropping out and the final COVID shutdown plus 1 collection missed because of missing equipment = 2 + 5 + 1 visits × 50 = 400 missing values) that the missing data were randomly distributed among different times of the day and night but that the data loss proportion was greater than the ideal proportions used clinically (i.e., having >85% complete data).³⁷ Our missing data rate (1,523 missing values) after allowance for the people in whom it was not collected (i.e., 400 missing measurements) was 71%, which is not as good as the 85% target. These missing data were due to equipment slippage and the failure of the blood pressure cuff to inflate properly.

Urinary analyses were part of the protocol that people could opt out of and some participants declined to consent. Table 2 reports we missed 16 of the potential urine samples we could theoretically have collected, and this is accounted for by five missed visits (5), plus two people opting out of urine in all visits (6), plus four people opting out of urine on one visit (4; one of whom was actually the final COVID-affected participant and we could not collect their sample because of the start of the Public Health Order that shut down research in the state and our study’s data collection phase), plus one missed sample (1) in conjunction with the staffing scheduling error (5 + 6 + 4 + 1 = 16). Two values for noradrenaline and 48 values for adrenaline were at the lower detectable limit.

HsCRP data were missing for 39/111 potential measurements. These are accounted for by five missed visits (5), the one visit cut short at the end by the public health order (1), plus one person opting out of all blood collection (3), plus one person opting out of blood on one visit (1), plus two people opting out of blood collection on two visits (4), 8 samples returned a value at or below the LODs and were entered as being missing data (0.1 mg/L; $n = 8$), and 17 samples were missing owing to insufficient blood volume collection to send for testing. There were no samples missing because of pathology service errors or a failed sample in transit (5 + 1 + 3 + 1 + 4 + 8 + 17 + 0 = 39).

Cortisol data were missing for 32/111 potential measurements. These are accounted for by five missed visits (5), the one visit cut short at the end by the public health order (1), plus one person opting out of all blood collection (3), plus one person opting out of blood on one visit (1), plus two people opting out of blood collection on two visits (4), and 18 samples were missing owing to insufficient blood volume collection to send for testing. There were no samples missing because of pathology service errors or a failed sample in transit or being below the LODs (5 + 1 + 3 + 1 + 4 + 18 + 0 = 32).

Glucose and insulin data were missing for 30/111 potential measurements. These are accounted for by five missed visits (5), the one visit cut short at the end by the public health order (1),

Table 2. Effects of infrasound and traffic noise on outcome measures in 37 participants in the in the laboratory-based three-arm crossover study of 72 h of exposure to simulated wind turbine infrasound, sham infrasound, and traffic noise ($n = 37$).

Variable	Units of measurement	Sham mean $\pm$ SEM; actual/potential obs	Infrasound mean $\pm$ SEM; actual/potential obs	Traffic mean $\pm$ SEM; actual/potential obs	Difference (95% CI), p -value infrasound vs. sham	Difference (95% CI), p -value traffic vs. sham
Wake after sleep onset	Min	24.49 $\pm$ 3.17; 107/111	23.13 $\pm$ 3.16; 108/111	30.56 $\pm$ 3.21; 101/111	-1.36 (-6.60, 3.88), 0.601	6.07 (0.75, 11.39), 0.02
Electrophysiological measurements of sleep (secondary outcomes)						
Sleep onset latency	Min	10.75 $\pm$ 2.3; 107/111	13.22 $\pm$ 2.2; 108/111	13.76 $\pm$ 2.3; 101/111	2.48 (-2.87, 7.82), 0.36	3.0 (-2.4, 8.4), 0.27
Arousal index	Events/h	8.79 $\pm$ 0.58; 107/111	9.08 $\pm$ 0.58; 108/111	9.13 $\pm$ 0.59; 101/111	0.29 (-0.58, 1.16), 0.51	0.34 (-0.54, 1.21), 0.45
Sleep stage % Wake	% of TST	8.7 $\pm$ 0.9; 107/111	8.6 $\pm$ 0.9; 108/111	10.0 $\pm$ 0.9; 101/111	-0.1 (-1.7, 1.6), 0.95	1.3 (-0.3, 3.0), 0.11
Sleep stage % N1	% of TST	6.3 $\pm$ 0.4; 107/111	6.5 $\pm$ 0.4; 108/111	6.9 $\pm$ 0.4; 101/111	0.2 (-0.3, 0.7), 0.49	0.6 (0.1, 1.1), 0.015
Sleep stage % N2	% of TST	40.6 $\pm$ 1.0; 107/111	39.4 $\pm$ 1.0; 108/111	41.6 $\pm$ 1.0; 101/111	-1.2 (-3.0, 0.6), 0.21	1.0 (-0.8, 2.9), 0.28
Sleep stage % N3	% of TST	23.1 $\pm$ 0.8; 107/111	22.4 $\pm$ 0.8; 108/111	20.8 $\pm$ 0.8; 101/111	-0.7 (-1.9, 0.4), 0.21	-2.4 (-3.5, -1.2), 0.0001
Sleep stage % REM	% of TST	21.3 $\pm$ 0.6; 107/111	22.8 $\pm$ 0.6; 108/111	20.8 $\pm$ 0.6; 101/111	1.5 (0.3, 2.7), 0.017	-0.5 (-1.7, 0.7), 0.42
Sleep stage shifts	Count	119.7 $\pm$ 4.8; 107/111	116.2 $\pm$ 4.8; 108/111	123.9 $\pm$ 4.8; 101/111	-3.5 (-9.5, 2.4), 0.24	4.2 (-1.8, 10.2), 0.17
Delta power—NREM	μV^2	481.68 $\pm$ 35.85; 106/111	487.28 $\pm$ 35.81; 107/111	467.10 $\pm$ 36.02; 100/111	5.61 (-27.04, 38.25), 0.74	-14.58 (-47.67, 18.52), 0.39
Theta power—NREM	μV^2	42.61 $\pm$ 2.53; 105/111	41.93 $\pm$ 2.53; 107/111	41.99 $\pm$ 2.53; 100/111	-0.68 (-2.36, 0.99), 0.42	-0.62 (-2.31, 1.08), 0.47
Alpha power—NREM	μV^2	20.47 $\pm$ 1.18; 105/111	20.54 $\pm$ 1.18; 107/111	20.04 $\pm$ 1.18; 100/111	0.07 (-0.82, 0.96), 0.87	-0.43 (-1.33, 0.47), 0.35
Sigma power—NREM	μV^2	12.55 $\pm$ 1.11; 105/111	12.40 $\pm$ 1.11; 107/111	12.54 $\pm$ 1.12; 100/111	-0.16 (-0.75, 0.44), 0.60	-0.01 (-0.61, 0.59), 0.97
Beta power—NREM	μV^2	10.95 $\pm$ 1.10; 105/111	8.99 $\pm$ 1.09; 107/111	11.06 $\pm$ 1.13; 100/111	-1.96 (-4.92, 1.01), 0.20	0.11 (-2.90, 3.12), 0.94
Delta power—REM	μV^2	113.28 $\pm$ 6.79; 105/111	118.20 $\pm$ 6.75; 107/111	109.07 $\pm$ 6.91; 99/111	4.92 (-6.17, 16.02), 0.38	-4.21 (-15.57, 7.14), 0.47
Theta power—REM	μV^2	25.74 $\pm$ 1.78; 105/111	25.74 $\pm$ 1.78; 107/111	25.14 $\pm$ 1.78; 99/111	0.00 (-1.14, 1.15), 1.00	-0.60 (-1.76, 0.57), 0.31
Alpha power—REM	μV^2	11.32 $\pm$ 0.68; 105/111	11.28 $\pm$ 0.68; 107/111	11.08 $\pm$ 0.68; 99/111	-0.04 (-0.54, 0.46), 0.87	-0.24 (-0.75, 0.26), 0.34
Sigma power—REM	μV^2	3.82 $\pm$ 0.24; 105/111	3.90 $\pm$ 0.24; 107/111	3.51 $\pm$ 0.24; 99/111	0.08 (-0.31, 0.47), 0.69	-0.31 (-0.71, 0.08), 0.12
Beta power—REM	μV^2	9.57 $\pm$ 0.92; 105/111	9.91 $\pm$ 0.90; 107/111	10.29 $\pm$ 0.93; 99/111	0.34 (-1.89, 2.57), 0.77	0.72 (-1.56, 3.00), 0.54
Spindles in NREM	Count	723.0 $\pm$ 57.5; 106/111	711.6 $\pm$ 57.5; 107/111	725.4 $\pm$ 57.7; 101/111	-11.5 (-53.9, 31.0), 0.60	2.4 (-40.5, 45.3), 0.91
Average Spindle density in NREM	Count/min	2.43 $\pm$ 0.19; 106/111	2.43 $\pm$ 0.19; 107/111	2.45 $\pm$ 0.19; 101/111	0.01 (-0.12, 0.14), 0.91	0.03 (-0.10, 0.16), 0.69
Average fast spindle density in NREM	Count/min	1.45 $\pm$ 0.17; 106/111	1.46 $\pm$ 0.17; 107/111	1.47 $\pm$ 0.17; 101/111	0.02 (-0.09, 0.12), 0.73	0.03 (-0.08, 0.13), 0.59
Average slow spindle density in NREM	Count/min	0.98 $\pm$ 0.14; 106/111	0.97 $\pm$ 0.14; 107/111	0.98 $\pm$ 0.14; 101/111	-0.01 (-0.10, 0.08), 0.81	-0.00 (-0.10, 0.09), 0.96
Cardiovascular measurements						
Pulse transit time	ms	67.7 $\pm$ 2.1; 33/37	65.9 $\pm$ 2.1; 36/37	67.7 $\pm$ 2.2; 30/37	-1.8 (-6.1, 2.5), 0.41	-0.0 (-4.5, 4.5), 0.99
Pulse wave velocity	m/s	7.55 $\pm$ 0.35; 33/37	8.05 $\pm$ 0.34; 36/37	7.41 $\pm$ 0.37; 30/37	0.50 (-0.26, 1.25), 0.20	-0.14 (-0.93, 0.66), 0.73
Reactive hyperemia (endothelial function test)	Index	0.78 $\pm$ 0.10; 35/37	1.78 $\pm$ 0.10; 32/37	1.70 $\pm$ 0.10; 33/37	0.00 (-0.24, 0.24), 0.97	-0.08 (-0.32, 0.16), 0.51
Blood pressure—systolic (24-h)	mmHg	113.9 $\pm$ 1.8; 1,212/1,850	111.9 $\pm$ 1.8; 1,246/1,850	112.6 $\pm$ 1.8; 1,196/1,850	-2.1 (-2.9, -1.2), <0.0001	-1.4 (-2.2, -0.5), 0.002
Blood pressure—diastolic (24-h)	mmHg	66.5 $\pm$ 1.3; 1,212/1,850	65.8 $\pm$ 1.3; 1,246/1,850	66.0 $\pm$ 1.3; 1,196/1,850	-0.6 (-1.3, 0.1), 0.07	-0.5 (-1.2, 0.3), 0.19
Heart rate	bpm	67.1 $\pm$ 1.3; 1,212/1,850	67.1 $\pm$ 1.3; 1,246/1,850	66.4 $\pm$ 1.3; 1,196/1,850	0.1 (-0.6, 0.7), 0.80	-0.6 (-1.3, 0.1), 0.07
Blood and urine measurements						
Serum cortisol	nmol/L	413 $\pm$ 30; 28/37	391 $\pm$ 32; 23/37	382 $\pm$ 30; 28/37	-23 (-74, 28), 0.38	-31 (-80, 17), 0.20
Glucose	mmol/L	4.9 $\pm$ 0.1; 28/37	4.9 $\pm$ 0.1; 24/37	4.9 $\pm$ 0.1; 29/37	0.0 (-0.1, 0.1), 0.88	0.0 (-0.1, 0.1), 0.88
Insulin	mU/L	9.5 $\pm$ 1.0; 28/37	7.7 $\pm$ 1.0; 24/37	10.0 $\pm$ 1.0; 29/37	-1.7 (-3.3, -0.2), 0.025	0.6 (-0.9, 2.0), 0.44
HsCRP	mg/L	2.1 $\pm$ 0.6; 27/37	1.9 $\pm$ 0.7; 20/37	2.1 $\pm$ 0.6; 25/37	-0.1 (-1.7, 1.4), 0.87	0.1 (-1.4, 1.5), 0.93
Urinary creatinine	nmol/24 h	11.3 $\pm$ 0.7; 31/37	11.6 $\pm$ 0.7; 32/37	11.3 $\pm$ 0.7; 32/37	0.3 (-0.8, 1.4), 0.54	0.0 (-1.0, 1.1), 0.95
Urinary noradrenaline (adjusted) ^a	nmol/24 h/creatinine	19.3 $\pm$ 2.2; 31/37	19.4 $\pm$ 2.2; 32/37	23.4 $\pm$ 2.2; 32/37	0.1 (-4.3, 4.4), 0.98	4.1 (-0.2, 8.4), 0.06
Urinary adrenaline (adjusted) ^a	nmol/24 h/creatinine	3.8 $\pm$ 0.3; 31/37	3.7 $\pm$ 0.3; 32/37	4.0 $\pm$ 0.3; 32/37	-0.1 (-0.8, 0.6), 0.81	0.2 (-0.5, 0.9), 0.49
Urinary dopamine (adjusted) ^a	nmol/24 h/creatinine	151.4 $\pm$ 10.8; 31/37	160.2 $\pm$ 10.8; 32/37	160.1 $\pm$ 10.8; 32/37	8.8 (-7.3, 25.0), 0.28	8.7 (-7.2, 24.7), 0.28
Electrophysiological measurements of wake (derived from the Karolinska Drowsiness Test)						
Eyes open—delta	μV^2	53.53 $\pm$ 4.35; 392/444	58.51 $\pm$ 4.32; 403/444	64.34 $\pm$ 4.42; 379/444	4.98 (-3.62, 13.58), 0.26	10.81 (2.06, 19.55), 0.016
Eyes open—theta	μV^2	21.61 $\pm$ 2.48; 392/444	22.50 $\pm$ 2.47; 403/444	22.68 $\pm$ 2.48; 379/444	0.89 (-0.16, 1.94), 0.095	1.07 (0.01, 2.13), 0.048
Eyes open—alpha	μV^2	24.97 $\pm$ 2.93; 392/444	24.57 $\pm$ 2.93; 403/444	24.48 $\pm$ 2.94; 379/444	-0.41 (-1.44, 0.63), 0.44	-0.50 (-1.55, 0.55), 0.35
Eyes open—sigma	μV^2	6.10 $\pm$ 0.59; 392/444	6.05 $\pm$ 0.59; 403/444	5.91 $\pm$ 0.59; 379/444	-0.04 (-0.25, 0.17), 0.69	-0.18 (-0.40, 0.03), 0.09
Eyes open—beta	μV^2	18.12 $\pm$ 1.31; 392/444	18.09 $\pm$ 1.30; 403/444	16.44 $\pm$ 1.31; 379/444	-0.02 (-1.33, 1.29), 0.97	-1.67 (-3.00, -0.34), 0.014
Eyes closed—delta	μV^2	49.04 $\pm$ 5.63; 391/444	59.28 $\pm$ 5.56; 403/444	50.96 $\pm$ 5.74; 378/444	10.24 (-2.46, 22.95), 0.11	1.93 (-11.01, 14.86), 0.77
Eyes closed—theta	μV^2	26.71 $\pm$ 3.03; 391/444	28.10 $\pm$ 3.03; 403/444	27.27 $\pm$ 3.04; 378/444	1.39 (-0.61, 3.39), 0.17	0.56 (-1.47, 2.59), 0.59
Eyes closed—alpha	μV^2	45.36 $\pm$ 4.62; 391/444	43.36 $\pm$ 4.62; 403/444	44.33 $\pm$ 4.63; 378/444	-2.00 (-3.95, -0.04), 0.045	-1.03 (-3.01, 0.96), 0.31
Eyes closed—sigma	μV^2	6.93 $\pm$ 0.64; 391/444	6.99 $\pm$ 0.64; 403/444	6.79 $\pm$ 0.64; 378/444	0.07 (-0.22, 0.35), 0.65	-0.14 (-0.43, 0.15), 0.33

Table 2. (Continued.)

Variable	Units of measurement	Sham mean $\pm$ SEM; actual/potential obs	Infrasound mean $\pm$ SEM; actual/potential obs	Traffic mean $\pm$ SEM; actual/potential obs	Difference (95% CI), p-value infrasound vs. sham	Difference (95% CI), p-value traffic vs. sham
Eyes closed—beta	μV^2	19.54 $\pm$ 1.36; 391/444	19.87 $\pm$ 1.36; 403/444	18.43 $\pm$ 1.37; 378/444	0.33 (–1.13, 1.78), 0.66	–1.11 (–2.59, 0.37), 0.14
Affective symptoms of WTS (based on a 5-factor PCA of the original 20 visual analog scales)						
Factor 1: Fatigue	Log-standardized	0.45 $\pm$ 0.01; 404/444	0.46 $\pm$ 0.01; 403/444	0.48 $\pm$ 0.01; 375/444	0.01 (–0.02, 0.05), 0.41	0.03 (–0.00, 0.07), 0.09
Factor 2: Irritability	Log-standardized	0.46 $\pm$ 0.01; 404/444	0.46 $\pm$ 0.01; 403/444	0.48 $\pm$ 0.01; 375/444	0.01 (–0.02, 0.04), 0.60	0.02 (–0.01, 0.05), 0.16
Factor 3: Nausea and Dizziness	Log-standardized	0.47 $\pm$ 0.01; 404/444	0.47 $\pm$ 0.01; 403/444	0.46 $\pm$ 0.01; 375/444	0.00 (–0.02, 0.03), 0.87	–0.02 (–0.04, 0.01), 0.19
Factor 4: Sleep disturbance	Log-standardized	0.46 $\pm$ 0.01; 404/444	0.46 $\pm$ 0.01; 403/444	0.48 $\pm$ 0.01; 375/444	0.00 (–0.02, 0.02), 0.96	0.02 (0.01, 0.04), 0.01
Factor 5: Tinnitus	Log-standardized	0.46 $\pm$ 0.01; 404/444	0.46 $\pm$ 0.01; 403/444	0.49 $\pm$ 0.01; 375/444	–0.00 (–0.03, 0.02), 0.79	0.03 (–0.00, 0.05), 0.09
Behavioral performance measures						
PVT reciprocal mean reaction time	1/s	3.78 $\pm$ 0.08; 407/444	3.78 $\pm$ 0.08; 412/444	3.79 $\pm$ 0.08; 390/444	0.00 (–0.05, 0.05), 0.99	0.01 (–0.04, 0.06), 0.83
Tower of London grand mean execution test	s	10.4 $\pm$ 0.6; 409/444	10.5 $\pm$ 0.6; 414/444	10.2 $\pm$ 0.6; 384/444	0.1 (–0.4, 0.7), 0.64	–0.1 (–0.7, 0.4), 0.62
Tower of London grand number of errors	%	5.7 $\pm$ 1.0; 409/444	5.9 $\pm$ 1.0; 414/444	6.7 $\pm$ 1.0; 384/444	0.2 (–0.9, 1.2), 0.75	0.9 (–0.1, 2.0), 0.08
N-back—total number correct	Count	40.4 $\pm$ 1.6; 403/444	40.9 $\pm$ 1.6; 411/444	41.5 $\pm$ 1.6; 379/444	0.5 (–0.2, 1.2), 0.20	1.1 (0.3, 1.8), 0.005
End-of-visit questionnaire						
Insomnia Severity Index (3-d modified)	Points	5.1 $\pm$ 0.8; 106/111	4.8 $\pm$ 0.8; 106/111	7.2 $\pm$ 0.8; 106/111	–0.2 (–1.4, 0.9), 0.68	2.1 (1.0, 3.3), <0.001
Warwick-Edinburgh Mental Wellbeing Scale	Points	53.6 $\pm$ 1.1; 106/111	55.4 $\pm$ 1.1; 106/111	53.6 $\pm$ 1.1; 106/111	1.8 (0.2, 3.5), 0.03	–0.0 (–1.7, 1.7), 0.99
Kessler-10	Points	13.9 $\pm$ 0.6; 106/111	13.9 $\pm$ 0.6; 106/111	13.9 $\pm$ 0.6; 106/111	0.0 (–0.8, 0.8), 1.00	0.1 (–0.8, 0.9), 0.89
Depression Anxiety Stress Scale—Depression	Points	3.4 $\pm$ 1.0; 106/111	3.3 $\pm$ 1.0; 106/111	4.2 $\pm$ 1.0; 106/111	–0.1 (–1.5, 1.3), 0.88	0.8 (–0.6, 2.2), 0.24
Depression Anxiety Stress Scale—Anxiety	Points	2.4 $\pm$ 0.5; 106/111	2.5 $\pm$ 0.5; 106/111	3.0 $\pm$ 0.5; 106/111	0.1 (–0.8, 1.0), 0.83	0.6 (–0.3, 1.5), 0.22
Depression Anxiety Stress Scale—Stress	Points	5.8 $\pm$ 1.0; 106/111	5.1 $\pm$ 1.0; 106/111	6.0 $\pm$ 1.0; 106/111	–0.8 (–2.1, 0.5), 0.23	0.2 (–1.1, 1.5), 0.76

Note: Actual/potential obs gives the amount of observed and recorded data being used by the mixed model compared with the potential number of observations (i.e., complete data) so readers can gauge how much missing data for each of the conditions the model is having to deal with. %, Percentage; alpha frequency band, 8–12 Hz; beta frequency band, 15–32 Hz; CI, confidence interval; delta frequency band, 0.5–4.5 Hz; HsCRP, highly sensitive C-reactive protein; N1, non-REM sleep stage 1; N2, non-REM sleep stage 2; N3, non-REM sleep stage 3; NREM, non-REM sleep; obs, observation; PCA, principal component analysis; PVT, psychomotor vigilance task (simple reaction time task); REM, rapid eye movement sleep; SEM, standard error of the mean; sigma frequency band, 12–15 Hz; theta frequency band, 4.5–8 Hz; TST, total sleep time; WTS, wind turbine syndrome.

^aUnit of measurement is the variable measured nmol/24 h divided (adjusted) by the simultaneously measured creatinine (mmol/24 h).

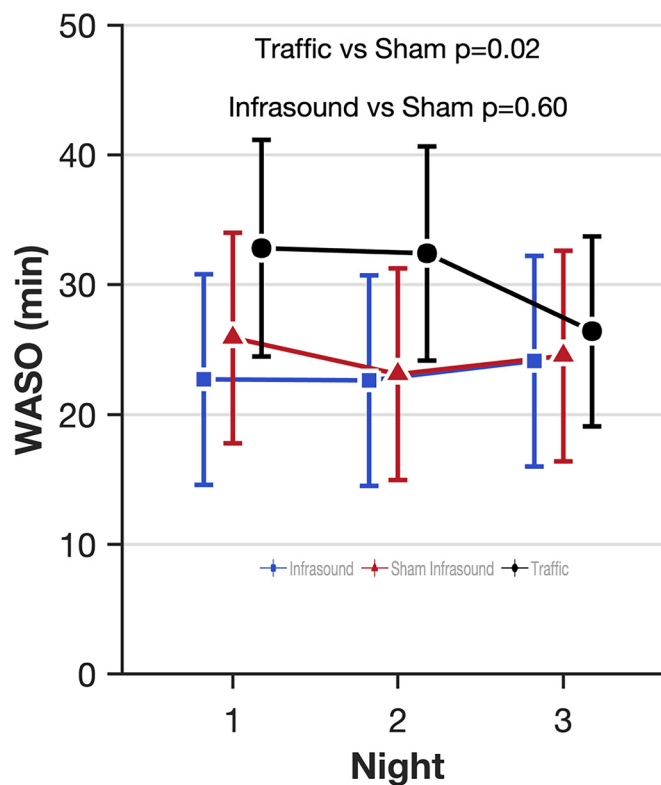


Figure 1. Effect estimates of infrasound and traffic on wake after sleep onset (WASO) over 3 nights in the laboratory-based study of the three-arm cross-over study of 72 h of exposure to simulated wind turbine infrasound, sham infrasound, and traffic noise. The mixed model estimates of the effect of infrasound and traffic noise on electrophysiologically measured human WASO. The primary outcome of this study was WASO as a measure of the effects of noise on sleep perturbation. WASO is the amount of time spent awake between sleep onset and final wake-up time. We measured sleep for 3 nights under each of the three exposures [infrasound in blue squares, sham infrasound in red triangles, and traffic noise in black circles; –1.36 min difference between infrasound and sham infrasound (95% CI: –6.60, 3.88, $p=0.601$); Table 2]. Error bars indicate the 95% CIs. Effects estimates are derived from mixed models of repeated measures where the participants were classed as random effects and exposure (3 levels), the order the exposure was received (1, 2, 3), the night of exposure (1, 2, 3), and interactions between the exposure by night and night by order as fixed effects. The least squares means procedure was used to address missing data. The exact numerical values for the estimated means and 95% CIs can be found in Table S3. Note: CI, confidence interval.

plus one person opting out of all blood collection (3), plus one person opting out of blood on one visit (1), plus two people opting out of blood collection on two visits (4), and 16 samples were missing owing to insufficient blood volume collection to send for testing. There were no samples missing because of pathology service errors or a failed sample in transit or being below the LODs ($5 + 1 + 3 + 1 + 4 + 16 + 0 = 30$).

Discussion

This study found that 72 h of the simulated wind turbine infrasound (~ 90 dB pk re 20 μ Pa) in controlled laboratory conditions did not worsen any measure of sleep quality compared with the same speakers being present but not generating infrasound (sham infrasound). The positive control condition, audible traffic noise (sound level of 40–50 dB LA_{eq,night} and 70 LAF_{max} transient maxima) worsened the primary measure of sleep quality, WASO, by ~ 6 min compared with the sham infrasound. This effect was evident on the first 2 nights where the magnitude of the effect is similar to a previous report.³⁸ The lack of an effect on the third

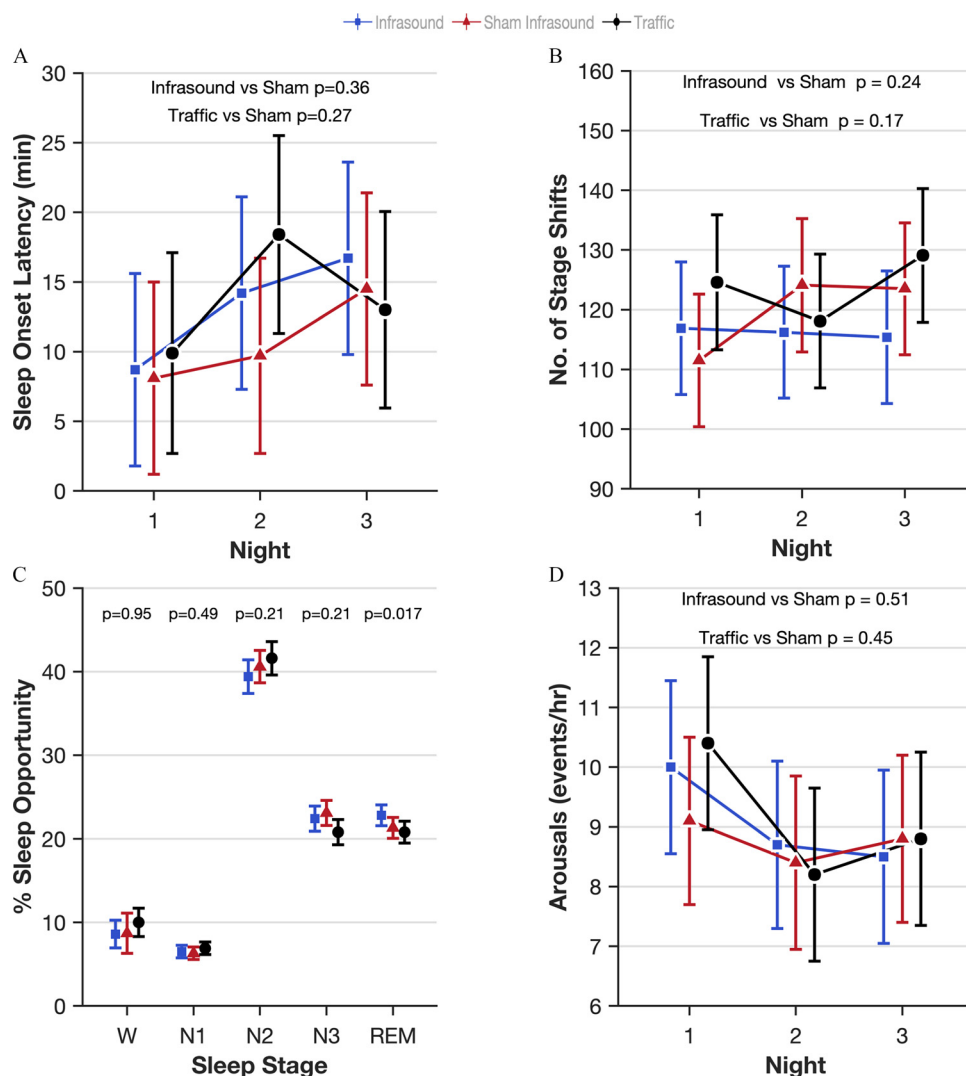


Figure 2. Effect estimates of infrasound and traffic on measures of sleep quality over 3 nights in the laboratory-based study of the three-arm crossover study of 72 h of exposure to simulated wind turbine infrasound, sham infrasound, and traffic noise. Infrasound is represented in blue squares, sham infrasound in red triangles, and traffic noise in black circles. Error bars are 95% CI. Effects estimates are derived from mixed models of repeated measures where the participants were classed as random effects and exposure (3 levels), the order the exposure was received (1, 2, 3), the night of exposure (1, 2, 3), and interactions between the exposure by night and night by order as fixed effects. The least squares means procedure was used to address missing data. The exact numerical values for the estimated means and 95% CIs can be found in Table S3. (A) Sleep onset latency is the amount of time taken to fall asleep [2.48 min difference between infrasound and sham (95% CI: $-2.87, 7.82, p = 0.36$); Table 2]. (B) Number of sleep stage shifts is a measure of sleep stability [-3.5 shifts difference between infrasound and sham (95% CI: $-9.5, 2.4, p = 0.24$)]. (C) Proportions of the sleep period scored as each of the traditional sleep stages plotted together to test whether infrasound causes perturbation to sleep depth. Numerical values above each plot are the p -values for the difference between infrasound and sham infrasound. p -Values above the stacked columns are comparing infrasound to sham infrasound. (D) Arousal index is the number of cortical arousals detected during each hour of sleep as a measure of sleep quality [0.29 events/h difference between infrasound and sham (95% CI: $-0.58, 1.16, p = 0.51$)]. Note: %, percentage; 1, non-REM sleep stage 1; 2, non-REM sleep stage 2; 3, non-REM sleep stage 3; CI, confidence interval; REM, rapid eye movement stage; SEM, standard error of the mean; W, wake.

night of traffic noise might have been caused by the build-up of homeostatic sleep pressure caused by the sleep disturbance on the first 2 nights.^{38,39} Furthermore, none of the staff or participants involved in the study reported being able to distinguish the infrasound condition from the sham infrasound and none of the participants displayed objective or subjective features consistent with WTS. From our list of 22 secondary outcome measures of sleep electrophysiology only one (% REM sleep) was significantly different in the infrasound exposure compared with sham. Furthermore, the effect estimate was in the opposite direction to that which was hypothesized and was not offset by changes in other sleep stages. As far as we can tell, this is the first study to investigate the effects on human sleep of simulated wind turbine infrasound in double-blind conditions.

We also measured the effects of infrasound on a wide range of nonsleep-related physiological and psychological measures. Four of the 39 tertiary outcomes we analyzed demonstrated an estimated effect of infrasound. These very small differences were not systematically in an adverse direction. Hence, we believe these effects have been detected by chance. We note that the design of the study, with many repeated measurements for each participant, meant there was a very high level of statistical power. Three of the measures (systolic blood pressure, insulin, and the Warwick–Edinburgh Mental Wellbeing Scale) improved by a small amount in association with exposure to infrasound compared with sham. In addition, the amount of alpha power during the eyes-closed condition of the Karolinska Drowsiness Test changed by a very small amount ($2 \mu V^2/s$, Cohens $d < 0.1$) in association with infrasound, and it is

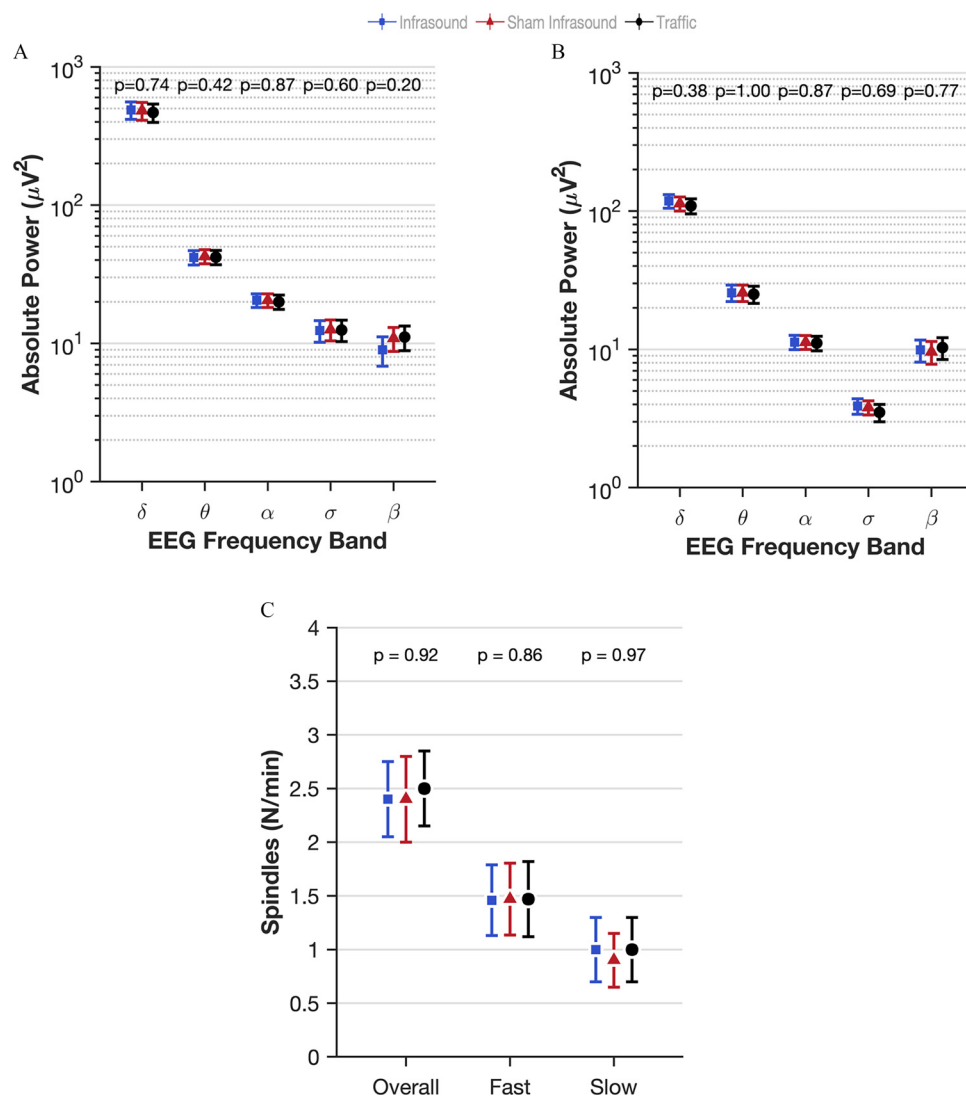


Figure 3. Effect estimates of infrasound and traffic on quantitative measures of electroencephalography during sleep in the laboratory-based study of the three-arm crossover study of 72 h of exposure to simulated wind turbine infrasound, sham infrasound, and traffic noise. Infrasound is represented in blue squares, sham infrasound in red triangles, and traffic noise in black circles. Absolute power derived from overnight electrophysiology transformed into five frequency bands as a measure of cortical activity in (A) NREM and (B) REM (delta δ = 0.5–4.5 Hz, theta θ = 4.5–8 Hz, alpha α = 8–12 Hz, sigma σ = 12–15 Hz, beta β = 15–32 Hz). Sleep spindle density in NREM overall and density of fast and slow spindles in NREM. (C) Fast spindle = 13–16 Hz and slow spindle = 11–13 Hz. Numerical values above each plot are the *p*-values for the difference between infrasound and sham infrasound. Effects estimates are derived from mixed models of repeated measures where the participants were classed as random effects and exposure (3 levels), the order the exposure was received (1, 2, 3), the night of exposure (1, 2, 3), and interactions between the exposure by night and night by order as fixed effects. The least squares means procedure was used to address missing data. The exact numerical values for the estimated means and 95% CIs can be found in Table S3. Point estimates are indicated graphically by the shapes and 95% CIs indicated by the bars. Note: CI, confidence interval; NREM, non-REM sleep; REM, rapid eye movement sleep.

not clear whether this direction of effect is helpful or harmful. We conclude that these findings suggest the absence of detectable health effects of infrasound on humans in our study.

People who suffer from WTS report that their symptoms begin quickly when they are exposed to infrasound from wind turbines and are then sustained.^{9,40} Our scientifically robust study provides evidence to address this claim. The Australian NHMRC report¹⁰ that gave rise to our study made note of this “absence of evidence” rather than concluding an “evidence of absence” owing to the lack of any laboratory-controlled double-blind experiments of sufficient duration and intensity to hypothetically induce WTS in a human. Our study attempted to address this absence of evidence by rigorously simulating wind turbine infrasound in the frequency range of 1.6–20 Hz at a sound level of ~90 dB pk re 20 μ Pa (measurable but inaudible) and comparing it in a double-

blind randomized exposure study to a sham infrasound exposure using the same equipment but with the speakers wired in anti-phase so that they did not generate infrasound. Furthermore, all previous studies we are aware of testing wind turbine infrasound (not audible WTN) in double-blind conditions have exposed people to 7.5 or 23 min of infrasound and not 72 h as we have here.^{15,16,18,41}

Our original sample size goal was 40 people, with an assumption that 2 people would drop out during the study. We actually randomized and analyzed data from 37 people and had 2 people drop out after completing only one of the planned three exposure periods before COVID forced us to close the study. The last participant, who was still in the study on the day it was closed, had completed both infrasound and sham infrasound conditions; therefore, we have not considered this person as having dropped

out. The power of the study remains strong owing to the triple-arm crossover design coupled with multiple repeated measurements of numerous physiological and psychological outcomes. For instance, the primary and secondary outcomes were measured nine times per person, which allowed us to estimate the difference between exposures for the primary outcome (WASO) within a span of ~ 9.5 min for the full width of the 95% confidence limit. The greatest number of repeated measures was for blood pressure where we collected ~ 150 blood pressure measurements across the three exposure per person. The width of the 95% confidence limits for the difference between exposures in 24-h systolic blood pressure measurement was only 1.7 mmHg. This helps improve our confidence that there are no meaningful adverse health effects of this specific formulation of infrasound in these humans. In addition, we found no evidence for a first-night effect in our primary outcome where humans often have a poor sleep in their first night in an unfamiliar laboratory environment compared with their subsequent stays.

The study has some limitations. It is possible that, despite the application of a noise-sensitivity eligibility criterion and also having seven participants who were somewhat concerned or concerned about the health effects of infrasound generated by wind turbines, we inadvertently recruited a group of people who were not sensitive to the effects of infrasound. It remains possible that some humans are sensitive to infrasound. This hypothesis has been tested in a short term study in double-blind conditions in people who said that wind turbines make them feel ill. Those participants were unable to reliably detect infrasound and did not physiologically react to it.⁴⁰ All of our quantitative electrophysiology measurements of the brain were taken from a single channel, so it remains possible that infrasound could have effects on other brain regions. It is also possible that our outcome measures lacked sensitivity for detecting adverse health effects of noise and the lack of effect of traffic noise on a number of secondary and tertiary outcome measures could be evidence for that lack of sensitivity. The background noise level in the sleeping environment created by the air-conditioning system was measured at about 39 dB LA_{eq}, which is above the recommended levels of the World Health Organization night noise guidelines of 35 dB LA_{eq} through the night and is louder than background recordings in sleep laboratories internationally that have undertaken noise exposure studies.⁴² This might have caused some sleep perturbation in some people that might have biased our results toward a null effect. However, we do not think that this would have been a powerful biasing effect. Our reasoning is that the sleep recordings in the people in this study when they were in the sham condition were in a very healthy range compared with reference values.⁴³ In addition, the sound levels in the two rooms used are experienced as a white noise background that is sometimes used by people as a sleep aid at considerably louder levels, albeit with a poor evidence base to be able to tell whether it is helpful or harmful.⁴⁴ Nevertheless, a background level of 39 dB LA_{eq} is somewhat louder than optimal for a control condition in a study of noise effects on sleep. However, on balance, we felt it was important to have a comfortable environment for the participants given many individuals in our country would have home air-conditioning or fans. Although the sham and traffic conditions might appear to be similar using averaged overnight sound pressure levels (39 dB LA_{eq,night} in the sham condition vs. 40–50 dB LA_{eq,night} in the traffic noise condition) they are actually quite different because the traffic noise includes infrequent, abrupt 70-dB LAF_{max} noise peaks designed to awaken humans (Figure S4). Presumably, if we had employed these noise maxima peaks more often we would have disrupted sleep to a greater degree. Our data completeness for our primary and secondary outcomes was high

and most data losses were at random and of small numbers, which can be dealt with by the statistical techniques we used. Our analyses of some tertiary outcome variables, including the blood-derived variables and the urinary catecholamines and also the heart rate and blood pressure data, should be interpreted with some caution given that they did suffer from higher than expected missing data proportions.³⁷

Conclusion

Our study found no evidence that 72 h of exposure to a sound level of ~ 90 dB pk re 20 μ Pa of simulated wind turbine infrasound in double-blind conditions perturbed any physiological or psychological variable. None of the 36 people exposed to infrasound developed what could be described as WTS. Our study is unique because it measured the effects of infrasound alone on sleep. This study suggests that the infrasound component of WTN is unlikely to be a cause of ill-health or sleep disruption, although this observation should be independently replicated.

Acknowledgments

The contributions of the authors were as follows: experiment design and application for funding (N.S.M., B.G.T., R.T., D.J.B., C.T.C., N.G., M.S.W., C.L.P., G.B.M., and R.R.G.), principal investigators (N.S.M. and R.R.G.), protocol development (N.S.M., G.C., and R.K.), lead study coordinator (G.C.), medical oversight (G.B.M. and R.R.G.), psychological screening (D.J.B.), audiological and neurological screening (C.R.W. and M.S.W.), staff coordination (G.C., B.G.T., and C.A.E.), grant budget control (B.G.T.), noise simulation speaker construction and acoustic engineering quality assurance and quality control (R.T. and O.J.), electroencephalography data quality and processing oversight (G.C. and A.L.D.), statistical analyses (N.S.M. and G.C.), manuscript drafting (N.S.M. and G.C.), and manuscript planning committee (N.S.M., B.G.T., R.T., G.B.M., and R.R.G.).

We acknowledge the people who collected or processed data: C. Berry, N. Hurst, E. Argæt, L. Fratturo, S. Theocharous, S. Haffar, B. Zhang, S. Shulka, M. Nguyen, I. Wood, J. Nguyen, H. Smith, N. Charlwood, C. Low, K. Kremerskothen, V. Fuchsova, B. Tiik, A. Bertolin, S. Yuhedran, A. Radowiecka, J. Ponahajba, E. Olszewska, M. Bronisz, C. Lorilla, M. Allado, N. Mutombe, H. Linn, M. Balenzuela, I. Basic, C. Geha, B. Pan, D. Jia, R. Wallis, K. O'Doherty, and I. Juria. We also acknowledge the members of the data safety monitoring board (DSMB): S. Loughran, G. Hamilton, S. O'Leary, and F. Garden (DSMB statistician), as well as the data engineers, G. Unger and Z. Zhou, and graphic design assistance, R. Wassing.

The funder played no role in the conduct of the study or the decision to publish.

Trial Registration: ANZCTR (ACTRN12617000001392).

Funding for this study was granted by the National Health and Medical Research Council of Australia (NHMRC) through the Targeted Call for Research into Wind Farms and Human health, APP1113615.

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Systematic review of the human health effects of wind farms

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© National Health and Medical Research Council, 2015

ISBN (online): 978-0-9923968-0-0

Internet site: <http://www.nhmrc.gov.au/>

The National Health and Medical Research Council commissioned this research from:

A/Prof Tracy Merlin	Adelaide Health Technology Assessment (AHTA)
Skye Newton	School of Population Health
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Joanne Milverton	Adelaide, South Australia
Claude Farah	

This document should be cited as:

Merlin, T, Newton, S, Ellery, B, Milverton, J & Farah, C 2015, *Systematic review of the human health effects of wind farms*, National Health and Medical Research Council, Canberra.

Conflicts of interest

The authors of this document have no financial or other conflicts of interest pertaining to wind farms or wind turbines.

Acknowledgments

We would like to acknowledge the comprehensive peer review of this document by the NHMRC Wind Farms and Human Health Reference Group and the methodological peer review undertaken by the National Collaborating Centre for Environmental Health (NCCEH, Canada); the feedback was helpful and contributed to the rigour of analysis and reporting in this document. With thanks to Ms Jessica Tyndall, Flinders University Librarian, for her assistance in developing the grey literature search; and Professor Persson Wayne for providing additional clarification with respect to her publications. This document was edited by Jo Mason at MasonEdit, Adelaide.

Minor amendments published in February 2015

The following amendments to the contents of this report were published in February 2015:

- Addition of a footnote in Table 27 and in Appendix B, indicating that the apparent error in the data presented in the table was directly transcribed from the source material (page 98 and page 251).
- A minor change to the definition of the term Odds Ratio in the Glossary (page 187).
- Minor corrections to data in the evidence tables in Appendix B (page 230 and page 240). These changes had no impact on the presentation or interpretation of results in the body of the report.

CONTENTS

EXECUTIVE SUMMARY	9
INTRODUCTION	19
Objective of the review	19
Rationale for the review	19
Review questions	21
Background review questions	21
Systematic review questions	22
WIND TURBINES AND WIND FARMS	24
Wind farms in Australia	24
How power is produced by wind turbines	25
REVIEW METHODOLOGY	27
Methodology to address background review questions	27
Methodology to address systematic review questions	30
Literature search strategy	30
Study selection criteria	31
Exclusion criteria	32
Process of literature selection	32
Critical appraisal of selected evidence	34
Data extraction and synthesis	38
Quality assurance	40
RESULTS OF SEARCHES	41
Background review questions (<i>mechanistic and parallel evidence</i>)	41
Systematic review questions (<i>direct evidence</i>)	41
NOISE	59
Sound perception and distance	61
Infrasound and low-frequency noise (ILFN)	62
Mechanisms by which noise might affect health	62
Sound from wind turbines	64
Measurement of sound from wind turbines	66

Systematic literature review	73
Association between wind turbine noise and physical health effects..	73
Association between wind turbine noise and mental health effects ...	78
Association between wind turbine noise and quality of life.....	81
Other relevant outcomes	83
Summary	100
Parallel evidence	106
Infrasound and low-frequency noise	108
Summary	121
SHADOW FLICKER.....	124
Predicting the extent of shadow flicker from a wind turbine	124
Frequency thresholds and seizure risk from shadow flicker or blade glint .	125
Systematic literature review	127
Summary	129
Parallel evidence.....	133
Summary	136
ELECTROMAGNETIC RADIATION	138
Levels of EMF emitted from wind turbines	139
Systematic literature review	140
Parallel evidence.....	141
Summary	158
WIND TURBINE EXPOSURE AND HUMAN HEALTH EFFECTS ASSESSED AGAINST MODIFIED BRADFORD HILL CAUSALITY GUIDELINES	160
ALTERNATIVE EXPLANATIONS FOR REPORTED ASSOCIATIONS	163
Attitudes towards wind farms	163
Visibility of turbines	163
Financial gain from the site of turbines.....	163
Community decision-making on site of turbines.....	164
Age and design of turbines	164
Nocebo effect	164

LIMITATIONS IN THE EVIDENCE-BASE AND SUGGESTIONS FOR FURTHER RESEARCH	165
ONGOING RESEARCH	166
International research	166
Australian research	167
CONCLUSIONS	169
Do wind turbines cause adverse health effects in humans?	169
REFERENCES	171
GLOSSARY AND ABBREVIATIONS	181
APPENDIX A – SEARCH STRATEGIES	196
APPENDIX B – EVIDENCE TABLES FOR INCLUDED ARTICLES.....	198
Study NL-07.....	200
Ontario, Canada, study	215
Australian study	220
Maine, USA study.....	223
New Zealand study	228
SWE-00 study.....	232
SWE-05 study.....	237
SWE-00 vs SWE-05 study	242
NL-07 vs SWE-00 vs SWE-05 study	248
APPENDIX C – EXCLUDED ARTICLES.....	254
Study design unsuitable.....	254
Study outcome(s) unsuitable	254
Duplicated study or data	255
Study exposure unsuitable	255
Study not in English language	256
Study comparator unsuitable	256
Article is not a study (wind energy discussion)	256
Article is not a study (commentary/opinion)	258
Article is not a study (narrative review)	259
Article is not a study (guidelines, regulations)	261

Article is not a study (wind turbine background)	262
APPENDIX D – SUMMARY OF LITERATURE PROVIDED BY THE NHMRC.....	264

TABLES

Table 1	Wind farms operating in Australia by commissioning date	25
Table 2	Search strategy and criteria for selecting evidence to inform Background Question 4	28
Table 3	Search terms to identify evidence to inform the systematic review questions	31
Table 4	NHMRC evidence hierarchy: designations of levels of evidence (excerpt)—aetiology research question only	38
Table 5	Conceptual framework to determine causality (modified Bradford Hill Guidelines).....	40
Table 6	Evidence map of literature obtained to answer the systematic review questions	44
Table 7	Profile of the studies included to address the systematic review questions (<i>critical appraisal adapted from NHMRC 2000, Box 9.1</i>)	46
Table 8	Sources of aerodynamic sound from a wind turbine.....	65
Table 9	Wind turbine measurements (conducted outdoors) by power, distance and conditions	67
Table 10	Australian state and territory noise level limits	71
Table 11	Association between estimated A-weighted sound pressure levels from wind turbines and specific physical health effects (OR, 95%CI)	75
Table 12	Association between distance from wind turbines (m) and physical health outcomes.....	76
Table 13	Estimated A-weighted sound pressure levels, age, gender and economic benefit, as possible independent predictors of health outcomes in multivariate models analysed in the Dutch study (NL-07).....	77
Table 14	Association between estimated A-weighted sound pressure levels and stress	79
Table 15	Relationship between estimated A-weighted sound pressure levels, other possible confounding factors and psychological distress or stress in study NL-07.....	80
Table 16	Relationship between distance and self-reported mental health	81

Table 17	Association between distance from a wind turbine and quality of life	82
Table 18	Association between estimated A-weighted sound pressure levels and sleep disturbance (OR, 95%CI)	84
Table 19	Relationship between estimated A-weighted sound pressure levels, other possible confounding factors and sleep quality in study NL-07.....	85
Table 20	Association between sleep quality and distance from nearest wind turbine	86
Table 21	Association between estimated A-weighted sound pressure levels (independent, continuous variables) and annoyance at wind turbine noise (OR, 95%CI)	89
Table 22	Association between estimated A-weighted sound pressure levels and annoyance (further details).....	91
Table 23	Association between distance from nearest wind turbine and annoyance or disturbance.....	92
Table 24	Associations of terrain, urbanisation and visual factors with annoyance from wind turbine noise in multiple logistic regression models	93
Table 25	Associations of noise sensitivity and attitudes to wind turbines with wind turbine noise annoyance	95
Table 26	Association between annoyance outdoors due to wind turbine noise and health outcomes	97
Table 27	Association between annoyance indoors due to wind turbine noise and health outcomes	98
Table 28	Independent predictors of annoyance from wind farms in the Dutch study (NL-07)	99
Table 29	Definitions of ‘sufficient’ and ‘limited’ evidence as per the WHO working group of the European Centre for Environment and Health	107
Table 30	Parallel evidence examining the association between infrasound and low-frequency noise (ILFN) and adverse health effects	110
Table 31	Profile of one study assessing shadow flicker	128
Table 32	Association between distance from wind turbine and annoyance at shadow flicker	129
Table 33	Parallel evidence examining the association between shadow flicker and adverse health effects	134

Table 34	Typical magnetic field strength of household appliances at various distances.....	140
Table 35	Magnetic field spot measurements at selected locations in 26 homes and percentage of homes (95%CI) for which the level exceeded 0.4 μT^a at that location	142
Table 36	Descriptive statistics for magnetic fields from selected appliances measured at a nominal 30-cm separation ^a	143
Table 37	Average levels of personal exposure (μT) to magnetic fields in occupational and non-occupational groups.....	144
Table 38	Parallel evidence examining the association between extremely low frequency electromagnetic fields (ELF) and adverse health effects.....	146
Table 39	Assessing the causal hypothesis using the modified Bradford Hill Guidelines.....	161
Table 40	Summary of literature received from the NHMRC	265

FIGURES

Figure ES. 1	Use of different types of evidence to support determination of causation (adapted from Howick, Glasziou and Aronson, 2009).....	10
Figure 1	Process of study selection according to eligibility criteria in Box 1	43
Figure 2	Standardised frequency weighting curves	60
Figure 3	G-weighting function across 1/3 octave band frequency (Hz)	61
Figure 4	Range of measured $L_{eq, 10 \text{ minutes}}$ infrasound levels at each measurement location.....	69

BOXES

Box 1	Criteria for selecting studies to assess the impact of wind farms on human health	33
Box 2	Rating method used to determine degree of support for an association	39
Box 3	Evidence statement matrix for noise	103
Box 4	Evidence statement matrix for shadow flicker	130

EXECUTIVE SUMMARY

Purpose

This independent review of the literature was commissioned by the National Health and Medical Research Council (NHMRC) to determine whether there is an association between exposure to wind farms and human health effects and, if so, whether this association is causal or might be explained by chance, bias or confounding.

Direct evidence of any health effects was obtained through a systematic literature review of all the available evidence on exposure to the physical emissions produced by wind turbines. The emissions investigated were: noise, shadow flicker and the electromagnetic radiation (EMR) produced by wind turbines.

A background literature review was also undertaken to establish whether there is basic biological evidence, or evidence from research into other circumstances of human exposure to the physical emissions that wind turbines produce, that makes it plausible that wind turbines cause adverse health effects.

Review questions

The review questions developed by the NHMRC Wind Farms and Human Health Reference Group (the Reference Group) are given on pages 21–23. A *background review* summarises general knowledge about a topic and is not intended to be answered comprehensively. A *systematic review* provides a transparent means for gathering, synthesising and appraising the findings of studies on a particular topic or question. The aim is to minimise the bias associated with the findings of single studies or non-systematic reviews. A systematic review provides a scientific analysis of all of the highest quality evidence available on a topic.

Method

A protocol was developed to guide the conduct of the reviews. It outlined the project scope, research questions, and for the systematic review questions it provided the criteria for selecting and critically appraising studies, templates for extracting data and methods for synthesising the results obtained from the evidence-base. The review methods differed depending on whether the question being addressed was a systematic or a background review question. The protocol incorporated suggestions from the Reference Group.

The protocol was closely followed in order to maintain transparency and, for the systematic review questions, to ensure that there was no bias in study selection, appraisal or interpretation. All of the evidence obtained was categorised and interpreted in the context of epidemiological guidelines developed by Austin Bradford Hill, and modified by Howick, Glasziou and Aronson (2009). These guidelines suggest complementing the available direct evidence of the impact of an exposure or intervention (such as wind turbines) on an

outcome (such as adverse health effects) with mechanistic and parallel evidence, in order to determine likely cause and effect (see Figure ES. 1 and Table 5, page 40). Mechanistic evidence consists of studies that investigate the alleged causal mechanism that connects the exposure to health outcomes. Parallel evidence consists of studies that investigate the effects of exposures that are similar to the exposure of interest. This evidence provides support for a causal hypothesis.

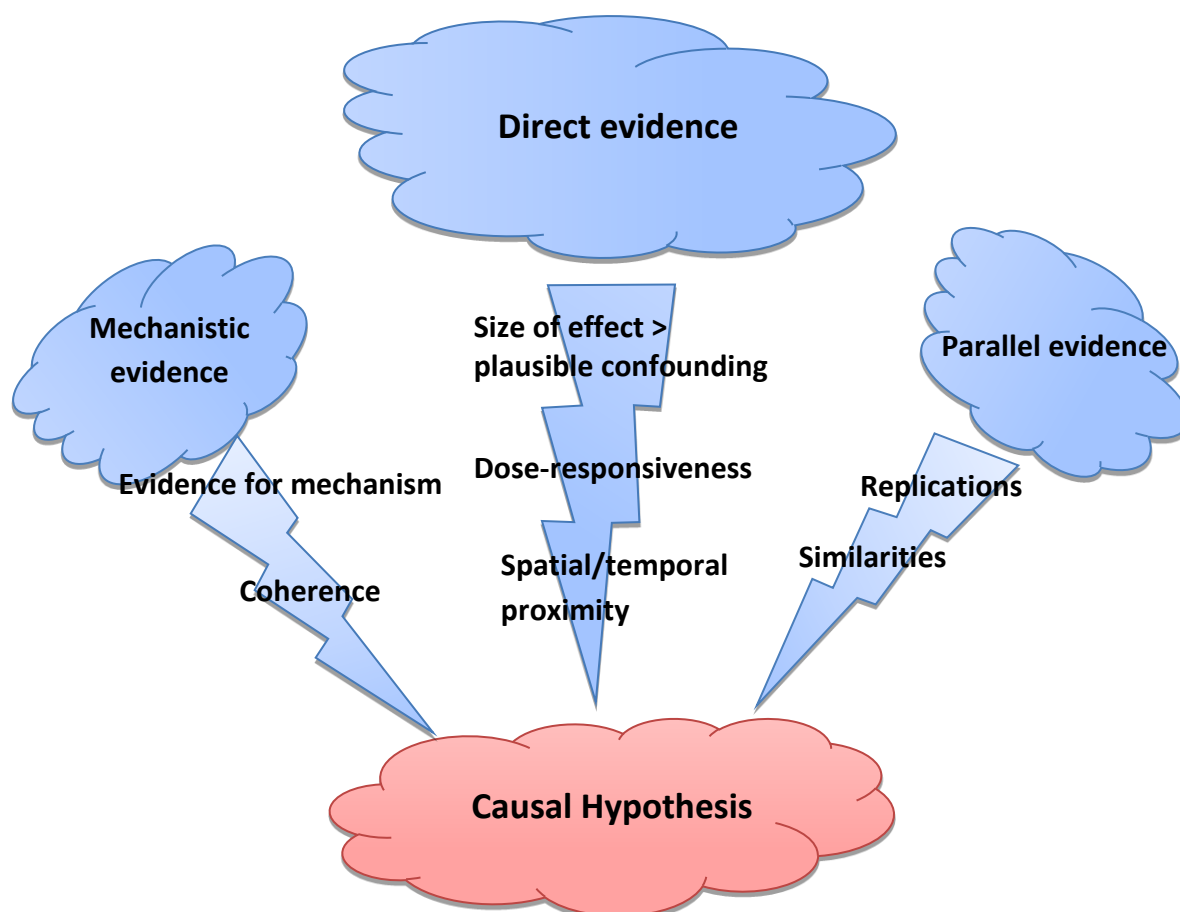


Figure ES. 1 Use of different types of evidence to support determination of causation (adapted from Howick, Glasziou and Aronson, 2009)

For this project the ‘direct evidence’ consisted of the evidence addressing the systematic literature review questions. The background review questions were concerned with the physiological mechanisms (‘mechanistic evidence’) by which noise, shadow flicker and EMR might produce adverse health effects, and whether any health effects have been observed from noise, shadow flicker and EMR produced by exposures other than wind turbines (‘parallel evidence’).

Within the conceptual framework offered by the modified Bradford Hill Guidelines, the direct evidence was assessed using an adaptation of the NHMRC FORM system for grading evidence (Hillier et al. 2011; NHMRC 2008). Studies were appraised in terms of their methodological rigour (level of evidence and likelihood of bias and confounding);

consistency of results; magnitude and precision of the estimates of human health effects; and generalisability and applicability of the findings to the Australian context. The findings from the mechanistic and parallel evidence were considered as 'Other Factors' that might upgrade or downgrade an evidence rating. Summary ratings were provided on a scale from A to D—an 'A' rating indicates that there is good support for an association between wind turbine emissions and human health effects, while a 'D' rating indicates poor support (Box 2, page 39).

Results

A comprehensive search of the peer-reviewed (black) and grey¹ literature was conducted and identified 2850 potentially relevant references. The NHMRC also provided 506 documents obtained from public submissions or from other sources. However, only 11 articles—reporting on 7 cross-sectional studies that investigated associations between wind turbines and health—met pre-specified eligibility criteria (Box 1, page 33) to address the systematic review questions. The process of study selection for the systematic review questions is given in a PRISMA (Preferred Reporting Items for Systematic reviews and Meta-analyses) flowchart (Figure 1, page 43). These studies provided the direct evidence-base to evaluate the impact of wind turbines on human health.

The studies were conducted in Sweden (SWE-00 and SWE-05), The Netherlands (NL-07), Australia (Morris 2012), New Zealand (Shepherd et al. 2011), Canada (Krogh et al. 2011) and the USA (Nissenbaum, Aramini & Hanning 2012). As there were several publications and re-analyses of data in the Swedish and Dutch studies, an evidence map has been provided in Table 6, page 44. All of the studies were level IV aetiological (causal) evidence², with a high risk of bias due to sample selection and lack of masking in some studies. There was a risk of outcome misclassification in all studies as the physical adverse health outcomes reported by study participants were not objectively verified (e.g. through the use of medical case notes). Age and gender were usually adjusted for in the analyses, but other possibly confounding factors were not consistently controlled. It is a significant limitation of the available evidence that it was not known whether any of the observed health effects in residents were present or occurring at a different intensity prior to wind turbine exposure (ie demonstrating appropriate temporal proximity).

Noise

Noise produced by wind turbines was discussed in all seven studies but infrasound and low-frequency noise (ILFN) were not specifically measured or discussed. One study (SWE-00)

¹ Definition is in the Glossary (source: <<http://www.greynet.org/greynethome/aboutgreynet.html>>).

² See

reported an association between estimated wind turbine sound pressure level (SPL) and self-reported tinnitus, and another study (SWE-05) reported a trend between SPL and self-reported diabetes. However, these findings were not replicated in the two other studies that assessed the same outcomes. It is possible that these isolated findings could have been due to differences in the distribution of possible confounders between exposure groups, or due to chance. None of the other physical health effects were found to be associated with estimated wind turbine SPL or distance from a wind turbine. Thus, associations of self-reported health effects with estimated noise exposure from wind turbines are inconsistent and possibly attributable to other factors.

The relationship between wind turbine proximity and quality of life was assessed by three studies. A New Zealand study (Shepherd et al. 2011) that attempted to mask respondents to the purpose of the survey and used a validated questionnaire reported that there was a significant association between distance from wind turbines and overall quality of life. Two other studies used author-formulated questions and did not mask the intent of the study, but found similar results. One Canadian study (Krogh et al. 2011) found that the majority of people reported that their quality of life had altered since living near a wind turbine, irrespective of their residential distance from a turbine (all lived within 2400 metres of a turbine). An American study undertaken in Maine (Nissenbaum, Aramini & Hanning 2012) reported a 74% difference in the number of residents wishing to move from the vicinity of a turbine (less than 1.4 km) when compared with residents living further away (over 3 km). The results of these studies were not adjusted for all plausible confounders, so it is unclear whether the association is due to wind turbine noise or other factors.

The results for possible associations between wind farm proximity and mental health measures were inconsistent. In the Maine study (Nissenbaum, Aramini & Hanning 2012) respondents who lived nearer wind farms reported statistically significantly poorer mental health, as measured by the SF-36 mental health component summary score, than those living further away. All participants in this study were aware that the study's purpose was to investigate the health effects of wind farms. In three of the four studies that provided contrary findings, the purpose of the research was masked from study participants. In these four studies there were no significant associations between estimated wind turbine noise exposure, or distance from a wind turbine, and levels of psychological distress, tension/stress, irritability, or self-reported depression and anxiety.

The association between estimated wind turbine noise and sleep was assessed by all seven included studies. Six of the seven studies reported poorer sleep—whether measured as higher rates of, or statistically significant differences in, sleep interruption or sleep quality—in those people with greater exposure to audible wind turbine noise³ or living a shorter distance from wind turbines. Only the study from Maine (Nissenbaum, Aramini &

³ Estimated A-weighted SPL

Hanning 2012) assessed reversibility, by asking respondents whether they had improved sleep when away from wind turbines. Half of those living less than 1.4 km from a wind turbine responded in the affirmative, compared with less than 6% of those who lived more than 3 km from a wind turbine.

No objective measures of sleep quality and sleep disturbance were used in these studies and the results were not adjusted for all plausible confounders e.g. annoyance and other factors that contribute to it. In the SWE-00, SWE-05 and NL-07 studies, the association between objective estimates of *sound pressure level* and sleep disturbance was not as strong as that between subjective assessments of wind turbine noise *annoyance* and sleep disturbance. In addition, some of the statistically significant differences in average sleep quality may not have been large enough to be meaningful.

Subjective levels of annoyance were consistently associated with wind turbine noise, both when outdoors and when indoors. Annoyance is not identified as a disease or health state, but it was still considered relevant to this systematic review because it is a universal negative human response to a condition or setting that may result in stress. Stress is a possible moderator or mediator of health outcomes. The five studies that assessed annoyance and noise exposure all reported statistically significant associations between annoyance and higher noise levels (estimated SPL) or residential proximity to a turbine. Rates of annoyance differed greatly between studies depending on level of estimated noise exposure, definition of annoyance (whether 'slightly annoyed' was classified as annoyed or not) and whether participants were masked to the study intent or not. The Dutch study (NL-07) found that 18% of respondents exposed to 35–45 dB(A) sound pressure were 'rather annoyed' or 'very annoyed' by wind turbine noise. A New Zealand study (Shepherd et al. 2011) reported that 59% of those living less than 2 km from a wind turbine were annoyed by the noise, while an Australian study (Morris 2012) reported that 56% of those living within 5 km of a wind turbine were disturbed by noise during the day.

The association between estimated noise level and annoyance was significantly affected by the visual attitude of the individual (i.e. whether they found wind farms beautiful, or ugly and unnatural) in the three studies that assessed this as a potential confounding factor (SWE-00, SWE-05, NL-07). Residents in the SWE-05 study with a negative attitude to the visual impact of wind farms on the landscape had over 14 times the odds of being annoyed compared with those people without a negative visual attitude. This was lower in the Dutch study (NL-07), ranging from 2.8 to 4.1 times the odds. Participants in SWE-00 reported that estimated SPL alone only accounted for 13% of the variance in the likelihood of annoyance, whereas estimated SPL plus visual attitude of the respondent accounted for 46% of the variance in annoyance. This means that factors other than the noise produced by wind turbines contribute to the annoyance experienced by survey respondents.

Systematic review evidence statement

There is no consistent evidence that noise from wind turbines—whether estimated in models or using distance as a proxy—is associated with self-reported human health effects. Isolated associations may be due to confounding, bias or chance.

There is consistent evidence that noise from wind turbines—whether estimated in models or using distance as a proxy—is associated with annoyance, and reasonable consistency that it is associated with sleep disturbance and poorer sleep quality and quality of life. However, it is unclear whether the observed associations are due to wind turbine noise or plausible confounders. (D rating)

Mechanistic and parallel evidence

Noise at high frequency lessens in intensity (loudness as measured by SPL) over much shorter distances than noise at lower frequencies. It does not pass easily through doors and windows—unlike ILFN, which can more easily pass through these obstacles. ILFN is, therefore, the exposure of most relevance at the range of distances typically observed between residential dwellings and commercial wind turbines. Hearing becomes gradually less sensitive as frequency decreases, so for humans to perceive infrasound and low frequency noise, the SPL needs to be high.

However, deriving a single SPL from wind turbines in the presence of background noise is difficult. The 2013 South Australian Environment Protection Authority study (Evans, Cooper & Lenchine 2013) measured infrasound at urban and rural locations and compared these with measurements taken at residences near two wind farms. Levels of background noise at residences near wind farms were also measured during organised shutdowns of the turbines. It was concluded that the level of infrasound at locations near wind farms was no greater than that experienced in other urban and rural environments. Further, the contribution of wind turbines to the measured infrasound levels taken at residences at a distance of approximately 1.5 km was insignificant in comparison with the background level of infrasound in the environment.

The available evidence addressing the background questions indicates that there are possible health effects from exposure to high audible noise levels, e.g. from road traffic (WHO 2011). However, as distance is closely related to estimated SPL, it is not expected that substantial audible noise exposures (>45 dB(A)) would be associated with modern wind turbines at distances of more than about 280 m (Ellenbogen et al. 2012), although this might vary by terrain, type of wind turbine and wind conditions. Sleep disturbance from noise exposure alone is not plausible at noise levels of 30 dB(A) and below, and has only modest effects at 40 dB(A) and below (WHO 2011).

The ILFN produced in the available laboratory studies was frequently greater than (usually A-weighted) 80 dB and ranged between 40 and 144 dB. Under these conservative conditions, ILFN appeared to have inconsistent and inconclusive effects on intermediate physiological measures taken from study participants. Health outcomes were not studied. Physiological changes such as heart rate, cortisol level, respiratory rate and blood pressure were measured. The data suggest that low-frequency noise at high SPLs may elicit a temporary threshold shift in hearing (Alford et al. 1966; Mills et al. 1983) and may lead to statistically significant, albeit very small and inconsistent, changes in systolic and diastolic blood pressure, and pulse or heart rate. There were too few studies reporting on exactly the same intervention or outcomes to determine if the results were replicable, and where studies were similarly designed there were inconsistent findings with respect to whether or not ILFN influenced physiological measures.

Shadow flicker

Direct evidence

No studies of good quality were identified that linked shadow flicker with adverse health outcomes. One small cross-sectional study (Morris 2012) with a high risk of bias reported on the association between shadow flicker and annoyance. Annoyed individuals reported symptoms of headache and blurred vision. Those living within 5 km of a wind turbine were more likely to report noticing shadow flicker, and being annoyed by it, than those who lived between 5 and 10 km from a wind turbine. No data on the rate of adverse outcomes, other than annoyance, were reported from this study. No conclusions could therefore be drawn regarding the association between adverse health outcomes and shadow flicker produced by wind turbines.

Mechanistic and parallel evidence

It is well recognised that shadow flicker exposure can affect health by inducing seizures in those prone to photosensitive epilepsy. This very rare condition can be induced by repetitive flashing lights and static repetitive geometric patterns, with the flicker inducing transient abnormal synchronised activity of brain cells and affecting consciousness, bodily movements and/or sensation. The timing, intensity and location of exposure to the shadow flicker produced by wind turbines is dependent on turbine size and shape, blade diameter, height of the sun and the blade direction relative to the observer. These variables are affected by wind direction and the time of day, time of year, and geographical location that the observation takes place. The Environment Protection and Heritage Council of Australia (EPHC 2010) estimate that the probability of a conventional horizontal-axis wind turbine causing an epileptic seizure due to shadow flicker is less than 1 in 10 million in the general population.

The sparse laboratory evidence available investigating the association between shadow flicker and health outcomes was of uncertain applicability to the shadow flicker conditions

produced by wind turbines. One study found no difference in stress-related outcomes between groups exposed and not exposed to shadow flicker but it could not be determined whether the flicker frequencies investigated were similar to those produced by wind turbines (Pohl, Faul & Mausfeld 1999). The other study found photoparoxysmal responses to a range of frequencies relevant to the flicker produced by wind turbines (>3 Hz) but the flicker exposure involved coloured light, rather than shadow, and all of the participants were photosensitive individuals (Shirakawa et al. 2001).

Electromagnetic radiation

Direct evidence

No studies were identified that specifically investigated an association between EMR (either extremely low-frequency (ELF) or other EMR frequencies) near wind farms and human health effects. Unless specified otherwise, reference to EMR in this section should be taken to be a reference the ELF EMR that is associated with alternating electrical currents.

Mechanistic and parallel evidence

Mechanistic studies indicate that the effects of external exposure to EMR on the human body and its cells depend mainly on the EMR frequency and strength (WHO 2002). It is known that the strength of an alternating electromagnetic field rapidly decreases as distance from the source increases (WHO 2012b). ELF EMR can produce eddy currents in human tissue. Since biochemical mechanisms and nerve transmission utilise electric impulses, exposure to ELF EMR could interfere with electrical currents that are vital to normal bodily function if the person is in close proximity to the source of the EMR.

In wind farms EMR is emitted from grid connection lines, underground collector network cabling, electrical transformers and turbine generators. However, there are scant data (one industry example only (Windrush Energy 2004)) on the magnitude and/or level (quantity) of EMR present in the vicinity of wind turbines. The available industry data suggests that the EMR levels near wind farms are likely to be within the range of EMR emitted by household appliances.

The applicability of the available parallel evidence on EMR to the wind farm context is uncertain. Concerns regarding the safety of EMR were raised with the publication of an early study reporting an association between the risk of childhood leukaemia and the degree of EMR exposure from electricity transmission lines (Wertheimer & Leeper 1979). Research has also been conducted on possible associations between occupational EMR and cancer or cardiovascular, neurological/psychological and reproductive diseases. However, apart from the study of childhood leukaemia, results from these EMR studies are characterised by a high degree of heterogeneity and are inconclusive (Ahlbom et al. 2001).

Other emissions

No other type of physical emission from wind farms that might cause adverse health effects was identified in the literature.

Conclusion

Direct evidence

In summary, the systematic review indicated that there was no consistent evidence that noise from wind turbines, whether estimated in models or using distance as a proxy, is associated with self-reported human health effects. The quality and quantity of the available evidence was limited.

Proximity to wind turbines or estimated SPL was associated with annoyance, and often associated with sleep disturbance and poorer quality of life. However, it cannot be ruled out that bias or confounding is an explanation for these associations.

Shadow flicker produced by wind turbines was found to be associated with annoyance in one small study, but health effects were not measured. There were no studies identified that investigated the impact on health of the EMR produced by wind turbines.

Mechanistic and parallel evidence

The information addressing the background review questions on possible mechanisms, and parallel circumstances, by which wind turbine emissions could impact on health was not persuasive. Although there were possible mechanisms by which shadow flicker and EMR could cause adverse health effects, the applicability of the available laboratory evidence to the wind turbine context could not be demonstrated.

Mid-to high frequency noise from wind turbines is unlikely to be significant at normal residential distances from wind turbines. ILFN from wind turbines is possible but difficult to isolate over the levels of background infrasound that are commonly present in the environment (e.g. wind noise in rural environments). The mechanism by which ILFN could cause adverse health effects is not clear and the available parallel laboratory evidence was inconclusive with regard to the effect on intermediate physiological outcomes as findings were inconsistent within and between studies.

Evidence for causation

To evaluate the strength of the evidence for a cause-and-effect relationship between wind turbine emissions (noise, shadow flicker and EMR) and adverse human health and health-related effects, the totality of the evidence was assessed in terms of the conceptual framework offered by the modified Bradford Hill Guidelines (Table 5, page 40).

The reported effects in the studies did occur near wind turbines (spatial proximity). However, with the exception of annoyance, sleep quality or sleep disturbance and quality of

life—the latter of which are possibly related to health—there was no consistent association between adverse health effects and estimated noise from wind turbines. Any isolated associations that were observed could have been due to plausible confounding or a spurious result from undertaking multiple statistical tests. Whether any of the reported effects followed the onset of exposure to wind turbines (temporal proximity) could not be ascertained because of the cross-sectional nature of the available studies. From these data, no dose-response relationship was observed between estimated sound pressure level or distance from a wind turbine and the direct health effects examined.

A dose-response relationship was apparent between wind turbine proximity and the possibly health related effects of sleep disturbance, poor sleep quality and quality of life; these effects were less common as the estimated SPL reduced or distance from the wind turbines increased. However, there is a possibility that the associations with sleep quality, sleep disturbance and quality of life are confounded by annoyance and other factors that determine it. Evidence of reversibility was present in one small study. Participants in this study recalled less sleep disturbance when they were away from wind turbines. The participants knew that the purpose of the study was to investigate wind turbine noise.

Possible mechanisms by which wind turbines could harm human health—and which are coherent with existing scientific theory—were plausible for shadow flicker and ELF EMR exposure but were of uncertain applicability to the wind turbine context. A mechanism by which ILFN could harm human health could not be determined. There was no consistent association observed between ILFN and intermediate physiologic effects (e.g. blood pressure) in the laboratory setting. Health outcomes were not measured.

The quality and quantity of evidence available to address the questions posed in this review was limited. The evidence considered does not support the conclusion that wind turbines have direct adverse effects on human health, as the criteria for causation have not been fulfilled. Indirect effects of wind farms on human health through sleep disturbance, reduced sleep quality, quality of life and perhaps annoyance are possible. Bias and confounding could, however, be possible explanations for the reported associations upon which this conclusion is based.

INTRODUCTION

Adelaide Health Technology Assessment (AHTA) was commissioned by the National Health and Medical Research Council (NHMRC) to conduct a review of the health effects of wind turbines on humans.

Objective of the review

The objective of the review was to determine whether there is an association between exposure to wind farms and human health effects and, if so, whether this association is causal or might be explained by chance, bias or confounding.

Rationale for the review

Wind turbines generate electricity using the wind and are promoted as a viable and sustainable alternative to traditional, non-renewable forms of energy production.

The presence of wind turbines in the environment is not without controversy, and many claims and counter claims of the negative health effects of turbines have been made. The issue is highly emotive, not only because of the controversy regarding negative effects on human health, but also because there are financial implications for land owners and power companies. These controversies have impacted on wind farm installation. For example, in South Australia, plans for two potential wind farms were either withdrawn by the company building them (as reported in *The Advertiser* on 23 August 2012) or refused planning permission by the local council (as reported on <www.abc.net.au/news> on 14 August 2012).

In 2010 the NHMRC produced a rapid review of the evidence on the health effects of wind turbines on humans (National Health and Medical Research Council 2010). The review investigated the potential health impact of the following turbine-related exposures:

- infrasound/noise
- electromagnetic interference
- shadow flicker
- blade glint

The review found ‘no direct pathological effects from wind farms’ while suggesting that ‘if planning guidelines are followed and communities are consulted with in a meaningful way, resistance to wind farms is likely to be reduced and annoyance and related health effects avoided’ (National Health and Medical Research Council 2010). The NHMRC’s Public Statement, *Wind turbines and health*, based on this review, indicated that, while there was currently no evidence linking the identified turbine-related exposures with adverse health effects, the evidence was limited (National Health and Medical Research Council 2010a).

The Public Statement recommended that relevant authorities take a precautionary approach and continue to monitor relevant research. It was suggested that compliance with standards relating to wind turbine design, manufacture and site evaluation would minimise any potential impacts of wind turbines on surrounding areas.

In 2011 a Senate Inquiry, 'The Social and Economic Impact of Rural Wind Farms', was conducted. The inquiry received more than 1000 submissions and held public hearings in four cities. It recommended a precautionary approach to noise standards, including conducting epidemiological and laboratory studies of the possible effects of wind farms on human health, as well as continuing the NHMRC review of research. The Australian Government accepted four of the seven recommendations of the inquiry, including supporting the recommendation that the NHMRC should continue the review of current research in the field, with regular publication of findings (Australian Government 2012).

In June 2011 the NHMRC held a forum on the issues related to the possible health effects of wind turbines⁴, leading to five major conclusions:

1. There is insufficient published, peer-reviewed, high-quality scientific evidence concerning infrasound and its effect on human health.
2. Research on infrasound and audible noise needs to include variables such as proximity to turbines, wind levels, topography and structure of residential housing.
3. Social and economic factors need to be considered when analysing the impact of wind farms on human health.
4. A thorough review should be conducted that evaluates the literature against defined levels of evidence, and highlights limitations in the available literature.
5. The review should consider all aspects of noise, including infrasound (less than 20 Hz) and audible noise (greater than 20 Hz).

Although there are many narrative reviews on the topic of wind farms (often produced by environmental protection or health authorities), none to date have addressed the topic using a formal evidence-based systematic literature review. This type of review requires a protocol or methodology to be developed prior to the review being undertaken, to provide transparency and thus potential replication of the review method, maintenance of impartiality and rigour in study selection, and formal standardised critical appraisal and synthesis of study results. A review of this type has been commissioned by the NHMRC in response to point 4 above, and is presented in this document. The NHMRC Wind Farms and Human Health Reference Group (the Reference Group) was established to oversee the proposed review. Depending on the outcomes of the review, the Reference Group will

⁴<<http://www.nhmrc.gov.au/media/events/2011/wind-farms-and-human-health-scientific-forum-7-june-2011>>

consider whether the NHMRC's 2010 Public Statement should be revised on the basis of the more robust and comprehensive evidence that this systematic review will provide.

Review questions

The Reference Group posed several questions to be answered by the review, and these were categorised as either background review questions or systematic review questions. A background review question seeks general knowledge about a topic and is not intended to be answered comprehensively. A systematic review question seeks a transparent means for gathering, synthesising and appraising the findings of studies on a particular topic. The aim is to minimise the bias associated with the findings of single studies or non-systematic reviews. It provides a scientific analysis of all of the highest quality evidence available on a topic.

Background review questions

A comprehensive background narrative was requested to answer the following questions:

- BQ1. What are wind turbines and wind farms?
- BQ2. By what specific physical emissions might wind turbines cause adverse health effects?
- BQ3. For each such emission, what is the level of exposure from a wind turbine and how does it vary by distance and characteristics of the terrain separating a wind turbine from potentially exposed people?
- BQ4. Is there basic biological evidence, or evidence from research into other circumstances of human exposure to physical emissions that wind turbines produce, that make it plausible that wind turbines cause adverse health effects?
- BQ5. Is there any direct research evidence that exposure to wind turbines is associated with adverse health effects?
- BQ6. If there is evidence that exposure to wind turbines is associated with adverse health effects:
 - a. Is there evidence that there are confounding factors or effect modifiers that might explain the association of wind turbines with adverse health effects? Such as but not necessarily limited to:
 - i. visibility of turbines
 - ii. financial gain from the siting of turbines
 - iii. community participation in decision making on the siting of turbines
 - iv. age and design of turbines?

Systematic review questions

The formal evidence-based questions were as follows:

Distance

- SQ1. Is there any reliable evidence of an association between distance from wind turbines and adverse health effects? If so:
- How strong is this association?
 - How does the strength of this association relate to distance from wind turbines?
 - Might this association be explained by:
 - chance?⁵
 - bias? or
 - confounding?

Audible noise

- SQ2. Is there any reliable evidence of an association between audible noise (greater than 20 Hz) from wind turbines and adverse health effects? If so:
- How strong is this association?
 - How does the strength of this association relate to level of exposure to audible noise from wind turbines?
 - Might this association be explained by:
 - chance?
 - bias? or
 - confounding?

Infrasound and low-frequency noise

- SQ3. Is there any reliable evidence of an association between infrasound and low-frequency noise (less than 20 Hz) from wind turbines and adverse health effects? If so:
- How strong is this association?
 - How does the strength of this association relate to level of exposure to infrasound/inaudible noise from wind turbines?
 - Might this association be explained by:
 - chance?
 - bias? or
 - confounding?

⁵ For definitions of *chance*, *bias* and *confounding*, please see Glossary and Methods sections.

Shadow flicker

SQ4. Is there any reliable evidence of an association between shadow flicker (photosensitivity⁶ greater than 3 Hz) from wind turbines and adverse health effects?

If so:

- a. How strong is this association?
- b. How does the strength of this association relate to level of exposure to shadow flicker from wind turbines?
- c. Might this association be explained by:
 - i. chance?
 - ii. bias? or
 - iii. confounding?

Electromagnetic radiation

SQ5. Is there any reliable evidence of an association between electromagnetic radiation from wind turbines and adverse health effects? If so:

- a. How strong is this association?
- b. How does the strength of this association relate to level of exposure to electromagnetic radiation from wind turbines?
- c. Might this association be explained by:
 - i. chance?
 - ii. bias? or
 - iii. confounding?

Areas that were out of scope for the review included:

- potential effects on human health from wind farm manufacturing and monitoring, such as occupational health and safety issues
- planning, development and monitoring activities related to wind farms
- the potential health effects of 'ice throw' and 'accident secondary to mechanical failure'.

⁶ Photosensitivity is an abnormal sensitivity to light stimuli, usually detected with electroencephalography (EEG) as a paroxysmal reaction to intermittent photic stimulation (IPS). The EEG response elicited by IPS or other visual stimuli of daily life is called photoparoxysmal response (PPR) (Verrotti et al. 2005).

WIND TURBINES AND WIND FARMS

BQ1. WHAT ARE WIND TURBINES AND WIND FARMS?

Wind occurs in response to the differential heating of parts of the earth and the earth's rotation. A wind turbine uses wind to produce electricity. There are two main types of wind turbine: the horizontal axis wind turbine (HAWT)⁷ and the vertical axis wind turbine (VAWT). HAWTs are more common because they are considered to be more efficient (Ali et al. 2011).

A group of wind turbines is known as a wind farm. A large wind farm may consist of several hundred individual wind turbines, cover a large geographical area and be located offshore or on land.

Wind farms in Australia

There has been a strong focus on wind power as an alternative to more traditional forms of energy production in Australia since the *Renewable Energy Act 2000* was legislated⁸. Wind power is considered to be a clean renewable energy source with no carbon dioxide emissions.

The first wind farm in Australia was constructed at Salmon Beach, Esperance (commissioned in March 1987), and consisted of six 60 kilowatt (kW) turbines (Ali et al. 2011). Towards the end of 2011 Australia had over 1 gigawatt (GW) of wind power installed (Table 1). By comparison, Europe had 57 GW operational in 2009 (European Wind Energy Association 2009).

The development of modern wind turbines has been an evolutionary design process, with performance optimisation occurring at many levels. Over the past 20 years wind turbines have evolved to minimise noise and to enable better exploitation of wind energy (Ellenbogen et al. 2012; Jakobsen 2005; Knopper & Ollson 2011). The majority of current large-scale wind turbines have a cylindrical tower structure (allowing internal access) and highly contoured turbine blades. Table 1 provides an overview of operational wind farms over 1 megawatt (MW) capacity in Australia until 2011 (Barry & Yeo 2011).

⁷ The rotor plane includes the blades, and the hub turns so that the wind is perpendicular to the plane.

⁸ <<http://www.comlaw.gov.au/Details/C2012C00858>>

Table 1 Wind farms operating in Australia by commissioning date

Commissioned	Project name	State	Developer	Size (MW)
1998	Crookwell	NSW	Eraring Energy	4.8
2000	Blayney	NSW	Eraring Energy	9.9
2000	Windy Hill	QLD	Stanwell	12.0
2001	Hampton	NSW	Wind Corporation Australia	1.3
2003	Starfish Hill	SA	Transfield Services	34.5
2004	Canunda	SA	International Power/Wind Prospect	46.0
2004	Lake Bonney Stage 1	SA	Infigen Energy	80.5
2005	Cathedral Rocks	SA	Hydro Tasmania & Acciona Energy	66.0
2005	Mount Millar (Yabmana)	SA	Tarong Energy, Transfield Services	70.0
2008	Hallett 1 (Brown Hill)	SA	AGL	94.5
2008	Lake Bonney Stage 2	SA	Infigen Energy	159.0
2008	Snowtown	SA	TrustPower	98.7
2009	Capital Wind Farm	NSW	Infigen Energy	140.7
2009	Cullerin Range	NSW	Origin Energy	30.0
2009	Hallett 2 (Hallett Hill)	SA	AGL	71.4
2009	Lake Bonney Stage 3	SA	Infigen Energy	39.0
2010	Clements Gap	SA	Pacific Hydro	56.7
2010	Waterloo	SA	Roaring 40s	111.0
2011	Hallett 4 (North Brown Hill)	SA	AGL	132.3

Source: Barry and Yeo (2011)

In Australia the state and territory governments oversee the placement of wind turbines. However, where there is a perceived threat to endangered or migratory animals, major wetlands or heritage sites, the federal government has regulatory powers (Haugen 2011).

How power is produced by wind turbines

Wind power is produced from the kinetic energy of air movement. Not all the available power in the wind can be captured by a wind turbine. The power available to a wind turbine can be estimated from the cube of the wind speed and the square of the rotor radius; that is, wind power is proportional to the third power of the wind velocity (Raymond 2012). To estimate the wind power captured by a wind turbine, both input and output wind velocities are crucial elements for consideration. Total wind power is captured only if the wind velocity is reduced to zero. However, in the practical setting, this is impossible to achieve as the captured air must also exit the turbine (Ellenbogen et al. 2012). Using Betz's law, it is

estimated in the literature that the maximum achievable wind power capture by a wind turbine is 59% of the total theoretical efficiency (Grogg 2005). Modern turbines have very large rotors to maximise the power obtained, noting that the number of rotor blades and tip speed also influence performance (i.e. solidity); however, trade-offs exist in terms of weight, cost and noise (Ellenbogen et al. 2012). Loss of energy from rotor blade friction and drag, gearbox losses, and generator and converter losses all contribute to reducing the power delivered by a wind turbine (Ellenbogen et al., 2012; Grogg 2005; Harding, Harding & Wilkins 2008; Hawkins 2012; Knopper & Ollson 2011).

REVIEW METHODOLOGY

A protocol was developed to guide the conduct of the project. It outlined the scope of the review, research questions, and for the systematic review questions it provided the criteria for selecting and critically appraising studies, templates for extracting data and methods for synthesising the results obtained from the evidence-base. The protocol was developed in conjunction with the Reference Group.

The protocol was closely followed throughout the conduct of the review, and the methods are described below. The review methods differed depending on whether the question being addressed was a systematic review question or a background review question.

Methodology to address background review questions

A broad literature search was conducted to inform Background Questions 1–3, and 6. This included basic information needed to understand the issues under investigation, along with information from peer-reviewed literature (i.e. narrative expert reviews and primary research reports) and technical reports and analyses produced by expert panels and environmental health agencies. It is important to note that this part of the review was not required to be performed systematically; thus, systematic searching and selection of studies was not undertaken. At the Reference Group's request, the aim was to provide a broad outline of the pertinent issues and to describe the circumstances under which wind farms operate and may impact on human health. The search was limited to information published after the establishment of the first commercial wind farm in 1981, and information was only included if it was relevant to humans and published in English. The search for relevant literature also included pearling⁹ of the reference lists of relevant reviews and reports, and snowballing¹⁰ to identify related pertinent literature. Background Question 5 was effectively answered by all the systematic review questions, and so it is not addressed or labelled separately in the Results section of this document.

Background Question 4¹¹ required a different approach. Although this question was not answered using a systematic literature review, as with the other background questions, a more systematic approach was applied given that it was about biological plausibility, and so could be material to the strength of conclusions arrived at using the proposed theoretical causality framework (page 40).

The literature search for Background Question 4 did not have chronological limits, but was limited to studies of humans that were published in English. To facilitate the identification of

⁹ Definition is in the Glossary.

¹⁰ Definition is in the Glossary.

¹¹ BQ4: Is there basic biological evidence, or evidence from research into other circumstances of human exposure to noise emissions, that make it plausible that wind turbines cause adverse health effects?

high-level evidence, only the peer-reviewed literature was eligible. Studies classified by the NHMRC evidence hierarchy (Merlin, Weston & Tooher 2009) (Table 4) as level I and II for aetiology studies were considered for this question; however, there was provision to look at lower level evidence if there was limited high-level evidence available. Given the restriction by study design and the exploratory nature of this background question, no formal quality appraisal was conducted. The search strategy for Background Question 4 is described in Table 2. If additional specific physical emissions related to wind turbines had been identified in Background Question 2, that were not covered by the search terms outlined in Table 2 (e.g. vibrations through the ground), additional searches would have been performed to assess these separately; however, this situation did not arise. Literature on each *a priori* identified exposure (audible sound, inaudible or low-frequency sound, shadow flicker and electromagnetic radiation) attributed to wind turbines was identified, and only studies that fulfilled the eligibility criteria were considered.

Table 2 Search strategy and criteria for selecting evidence to inform Background Question 4

Question: are there human health effects associated with:	Search terms for PubMed and Embase	Eligibility criteria
Audible noise (greater than or equal to 20 Hz)	1) PubMed: "Noise/adverse effects"[Mesh] AND (Cohort studies[Mesh] OR cohort analysis) 2) PubMed: "Noise/adverse effects"[Mesh] AND systematic[sb] 3) Embase: 'noise injury'/exp AND 'human'/de AND ('article'/it OR 'review'/it) AND [english]/lim ('clinical trial'/de OR 'cohort analysis'/de OR 'controlled clinical trial'/de OR 'controlled study'/de OR 'longitudinal study'/de OR 'prospective study'/de OR 'randomized controlled trial'/de) AND [humans]/lim AND [english]/lim	Level I evidence: systematic reviews of level II evidence; level II evidence: prospective cohort studies ^a Limited to studies of humans and those in English No chronological limits
Infrasound (less than 20 Hz)		
Shadow flicker (photosensitivity greater than 3 Hz)	1) PubMed: ("shadow flicker" OR photic stimulation/adverse effects OR seizures/etiology OR epilepsy reflex/etiology) AND (Cohort studies[Mesh] OR cohort analysis) 2) PubMed: ("shadow flicker" OR photic stimulation/adverse effects OR seizures/etiology OR epilepsy	

	reflex/etiology) AND systematic[sb] 3) Embase: ('shadow flicker' OR 'shadow' OR 'flicker') AND ('photic stimulation'/exp OR 'seizure'/exp OR 'seizure susceptibility'/exp OR 'adverse effects' OR annoyance) AND 'human'/de AND ('article'/it OR 'review'/it) AND [english]/lim ('clinical trial'/de OR 'cohort analysis'/de OR 'controlled clinical trial'/de OR 'controlled study'/de OR 'longitudinal study'/de OR 'prospective study'/de OR 'randomized controlled trial'/de) AND [humans]/lim AND [english]/lim	
Electromagnetic radiation	1) PubMed: ("Electromagnetic fields/adverse effects"[Mesh] AND "electric power supplies/adverse effects"[Mesh]) AND (Cohort studies[Mesh] OR cohort analysis) 2) PubMed: ("Electromagnetic fields/adverse effects"[Mesh] AND "electric power supplies/adverse effects"[Mesh]) AND systematic[sb] 3) Embase: ('Electromagnetic field'/exp AND 'power supply'/exp) AND 'human'/de AND ('article'/it OR 'review'/it) AND [english]/lim ('clinical trial'/de OR 'cohort analysis'/de OR 'controlled clinical trial'/de OR 'controlled study'/de OR 'longitudinal study'/de OR 'prospective study'/de OR 'randomized controlled trial'/de) AND [humans]/lim AND [english]/lim	

^a Due to limited level I or level II evidence being identified, the review included studies of lower level evidence (level III-1 and III-2). As no case-control studies (level III-3) were identified, these were not included. See Table 30, Table 33 and Table 38 for study details.

Background Question 6 and the systematic review questions had a similar focus on the effect of potential confounding factors on observed associations between wind turbines and adverse health effects. Where there was overlap in the questions, this was labelled

accordingly in the Results section of the report. When there was no element of overlap between the systematic review questions and Background Question 6, the questions were labelled separately in the Results section of the report.

Methodology to address systematic review questions

Literature search strategy

The search strategy for the systematic review investigated both the peer-reviewed (black) literature and grey literature¹². Grey literature sources often include a combination of both black and grey literature, and black literature often includes grey literature that has subsequently been published, so overlap in results between the two search strategies was expected.

The search canvassed the following databases: PubMed, Embase.com, The Cochrane Library, Psycinfo and Web of Science (the latter refined by health-related web of science categories, e.g. public/environmental/occupational health). Relevant papers had their reference lists perused for papers that may have been missed in the searches. The search was limited to papers that were published after the first commercial wind farm was established in 1981, involved humans and were published in English. Searches of the peer-reviewed literature were not restricted according to study design.

Scoping searches revealed a paucity of peer-reviewed studies; therefore, the search terms were kept broad to ensure that no studies were missed. It was considered likely that the available literature would consist primarily of observational studies¹³. The search strategy for the peer-reviewed literature is described in Table 3, using the example of the Medical Subject Headings (MeSH) appropriate for PubMed. Equivalent indexing terms were used for other databases.

¹² Definition is in the Glossary (source: <http://www.greynet.org/greynethome/aboutgreynet.html>).

¹³ It was not expected that experimental evidence (e.g. from randomised controlled trials) would be available to inform the systematic review questions.

Table 3 Search terms to identify evidence to inform the systematic review questions

Peer-reviewed literature search terms (PubMed example)
(wind[all fields] AND (turbine*[all fields] OR farm[all fields] OR farms[all fields] OR tower*[all fields] OR energy[all fields] OR technology[all fields] OR energy generating resources[MeSH] OR electric power supplies[MeSH])) OR wind turbine syndrome[all fields] OR Wind power[all fields]
Limits: 1981 – 10/2012; English language; human studies

Scoping searches indicated that there was a considerable amount of grey literature available on this topic. The grey literature search included use of Google Scholar, databases of conference proceedings, known grey literature sources, and selected government and scientific association websites (see APPENDIX A). The search strategy also included pearling of relevant reviews and reports and snowballing techniques to locate articles and reports in obscure locations.

In addition to literature obtained through these methods, NHMRC had called for public submissions of relevant non-peer-reviewed literature to inform the systematic review. These submissions were only eligible for consideration if they were:

- publicly available from a readily accessible source;
- described the systematic collection and analysis of data; and
- reported analytical results that were relevant to wind farms and human health.

Literature, whether peer reviewed or not, was not eligible for consideration if:

- the observations lacked organisation or analysis;
- it was an expression of opinion and was not based on the results of research; or
- it was based solely on haphazardly collected or unstructured personal testimony.

Public submissions to the NHMRC that met these screening criteria were then assessed as to whether they addressed the systematic review questions. This was determined using selection criteria pre-specified in the protocol for the review (see below and Box 1).

Study selection criteria

Studies eligible for inclusion in the systematic review had one of the designs described in the NHMRC evidence hierarchy for aetiology questions (Table 4), including systematic reviews of each of the study designs. These designs were eligible because they allow the impact of an exposure on health outcomes to be measured. Level IV studies were included if they were cross-sectional studies that provided results for respondents who were exposed to different sound pressure levels (SPLs) or who were living at different distances from wind turbines; that is, subgroup analysis according to level of exposure (for which distance from

wind turbines is a surrogate) was allowed. Studies without a within-group or between-group comparison (i.e. case series¹⁴) were excluded on the advice of the Reference Group. The Reference Group was aware of literature stating that case reports should be considered when assessing the health effects of wind turbines (Phillips 2011). However, individual case reports and collations of case reports (e.g. where all participants were selected because they had a health problem they attributed to wind turbines) were excluded from this systematic review because they provide no *objective* information by which reported health problems could be related to presence of, or amount of exposure to, wind turbines. Case reports and case series can be useful in generating hypotheses about the health effects of particular exposures, but they are not useful for testing these hypotheses except where a causal connection between exposure and health outcome is self-evident from the report (as, e.g., in the case of the ‘mother’s kiss’; Howick, Glasziou & Aronson 2009).

Examples of literature identified as opinion pieces, editorials or other papers without a clear study design and description of methods and results were not included. No limitations were placed on study outcomes—any study that had any type of adverse health effect as an outcome was eligible for inclusion in the review. These criteria were delineated using the PECOT structure¹⁵, which is appropriate to the assessment of epidemiological studies that would be addressing each of the systematic review questions (see Box 1).

Exclusion criteria

Studies were excluded if:

- They could not be located within the time allowed for the review;
- They exclusively studied a sample of people who had health or annoyance complaints that they attributed to wind turbines / wind farms; or
- There was no comparison group; that is, the results were not divided into two or more different exposure groups according to distance from wind turbines or SPL.

Process of literature selection

The literature selection process is depicted through a modified PRISMA flowchart (Figure 1) (Liberati et al. 2009) that separates out the grey and black literature and indicates the amount of cross-over between passive searching (literature submitted to the NHMRC) and active searching. Literature was initially screened conservatively¹⁶ by one reviewer for each of the grey and black literature searches, on the basis of the collated study titles and abstracts. Different reviewers were used to screen each of the searches as it was considered

¹⁴ Definition is in the Glossary.

¹⁵ Population/participants, Exposure, Comparator, Outcomes, Time

¹⁶ If the paper simply related to wind turbines and health, or related, effects it was included at the screening stage.

likely that there would be overlap in the literature that was identified by the searches and duplicate screening is preferred if the resources and time are available. Full papers of the studies deemed potentially eligible were then retrieved and independently assessed for inclusion by two reviewers. Where there was doubt about study eligibility, two senior reviewers read the paper and there was discussion between all four reviewers until a consensus decision was made. Studies that met the inclusion criteria in Box 1, but were subsequently excluded, are listed in APPENDIX C and categorised by their reason for exclusion.

Box 1 Criteria for selecting studies to assess the impact of wind farms on human health

Characteristic	Inclusion criteria
Study design	Studies with the designs described in Table 4 were included. ^a
Population/participants	People living within proximity of a wind farm / wind turbines <i>Subgroup analysis by distance from wind farm / wind turbine</i>
Exposure	Physical emissions produced by wind farms / wind turbines, specifically: • noise (≥ 20 Hz) • infrasound (< 20 Hz) • shadow flicker (photosensitivity > 3 Hz) • electromagnetic radiation <i>Subgroup analysis by level of exposure^b for each of these exposures.</i>
Comparator / control (if included)	No exposure to the physical emissions produced by wind farms / wind turbines, i.e. people not living within proximity of a wind farm / wind turbine
Outcomes	Any reported adverse health effects
Time	No restriction on the time period within which adverse health effects can be reported, with the exception that they should occur subsequent to the exposure
Search period	1981 ^c – 10/2012
Language	English language only

^a Case series were excluded on the advice of the Reference Group, given the lack of any comparison group.

^b Exposure rate or cumulative exposure (i.e. intensity or intensity x duration).

^c First commercial wind farm established.

Critical appraisal of selected evidence

Each systematic review question asked whether an observed association was likely to be due to bias, confounding or chance.

Bias is defined in the Glossary (page 181) as a systematic deviation of results or inferences from truth. In a study it relates to *an inaccuracy that differs in its size or direction in one of the groups under study than in the others ... this is a serious problem as bias can influence the results of a study in any direction. It can produce measurements of association that are exaggerated, and may produce strong associations when there is no true difference between the groups being compared.* (Elwood 2010)

Bias often occurs when there is a systematic difference between groups in the method used to assess a health outcome, whether by the person being studied, the investigator or an observer. The main principle in avoiding bias is to ensure that the same methods are used under the same circumstances for all people involved in the study. This can be achieved, where possible, through double- or single-masking techniques; that is, so that the research subject and/or the researcher are not aware of the exposure status when determining the outcome, or vice versa. This is sometimes too difficult to achieve, in which case the choice of outcome measure is important. The outcome measures must not only be relevant to the causal hypothesis, but must also be chosen to be objective, reproducible and robust (i.e. unlikely to be influenced by variations in the method of testing) (Elwood 2010).

Confounding is defined as *the distortion of a measure of the effect of an exposure on an outcome due to the association of the exposure with other factors that influence the occurrence of the outcome* (International Epidemiological Association 2008). Several factors were considered to be plausible confounders of 'adverse health effects', the outcome of interest in the systematic review. These plausible confounders were identified in the protocol that guided the systematic review:

- Age – If elderly people are more likely to develop heart disease (outcome) than younger people, and by chance the people living near a wind farm (exposure) who answered a health impact survey consisted of more elderly people than those living further away, it could appear that wind farm exposure was related to the development of heart disease. However, this might simply be an artefact of the unequal distribution of elderly residents in the two groups being compared.
- Gender – Risks of certain health effects (e.g. heart disease, migraine, certain cancers) are often higher in one sex than the other. Thus, a different distribution of male and female study participants in those living close to wind turbines from those living further away might result in an apparent association between wind turbine exposure and a health effect that was wholly or partly an artefact of the variation in gender distribution.

- Education – People with a poorer education often have a poorer health status, perhaps through lack of knowledge about appropriate prevention and management strategies. If there is a different distribution of people with primary, secondary and tertiary schooling according to their proximity to wind turbines, then it may result in an apparent association between wind turbine exposure and a health effect that was wholly or partly due to variation in educational attainment.
- Chronic disease – If study participants with pre-existing comorbidities and ailments or existing medication use were more likely to be located in areas designated for wind turbine construction or likely to move to an area that is near a wind turbine, this might give the appearance of an association between adverse health effects and wind turbine exposure. Similarly, differential distribution of study participants with behavioural and other risk factors for chronic disease, by distance from wind farms, could also result in an apparent association between wind turbine exposure and adverse health effects. Such risk factors include smoking (because of its relationship with numerous diseases, such as heart and other cardiovascular diseases, many lung diseases and a number of cancers) and overweight and obesity (because of their relationship with diabetes, sleep apnoea and heart disease). It is possible that there would be differences in the frequencies of these risk factors between study participants living at different distances from wind farms. It is known, for example, that people living in rural and remote regions of Australia, where wind farms are more likely to be located, often have higher rates of obesity, alcohol use and smoking than those living in more urban settings¹⁷. This might also be the case in other countries.
- Occupation – People who undertake shift work often have more disturbed sleep patterns and poorer health outcomes than people working ‘normal’ hours. Similarly, certain occupations are associated with particular health risk factors and diseases (e.g. mining and lung diseases). Therefore, if the distribution of occupations of study participants varies according to wind turbine proximity, it is possible that any apparent associations of wind turbines and health outcomes are the result of differences in ‘worker profile’ between those who live close to wind turbines or at a distance.
- Economic factors – The risk factors mentioned above are also more common in people of lower socioeconomic status (SES). People of lower SES tend to have a higher risk of many diseases, partly because of a greater likelihood of having disease risk factors (such as smoking, excessive use of alcohol and overweight or obesity) but also because of less tangible factors, such as their “status” in society. These people may be less likely to take actions that might prevent disease and to have less access to services that maintain health or control disease (which may also occur

¹⁷ <http://www.aihw.gov.au/rural-health-risk-factors/>

with remoteness of residence). SES might confound associations between exposure to wind turbines and health effects in at least two ways. First, it is plausible that a higher proportion of people living close to wind turbines are gaining financially from having turbines sited on their land and that confounding of economic gain with wind turbine exposure might lead to fewer health effects in people living near wind farms. Second, there might be a higher proportion of people of lower SES living close to wind turbines because those of higher SES have been able to move away. While this, of itself, would increase the proportion of lower SES people close to wind turbines, the movement of higher SES people could lead to lower cost housing nearer wind turbines and attract lower SES people there.

Other factors identified and addressed in some of the studies collated for this review include terrain, urbanisation, background noise, noise sensitivity, turbine visibility, household clustering, housing, and residence duration. Depending on the associations being tested, some of these factors were considered as potential confounders of health outcomes, while others were considered as potential confounders of annoyance outcomes.

Confounding can be prevented by prospectively randomly allocating people to the different groups—if the sample size is large enough, both known and unknown confounders will generally be equally distributed between the exposure groups. It can also be prospectively addressed in cohort studies through matching individuals in the different groups according to known confounders. Neither of these study designs was presented in the direct evidence available for this review.

In observational studies of the kind typically provided to investigate the association of wind turbine exposure and adverse health effects in this review, confounding was usually addressed by analysis within strata of the confounding variable, or statistical adjustment (usually by way of a regression model of some kind) of the observed results for the effects of one or more measured confounders. Unknown or unmeasured confounders cannot be controlled in such studies and control of measured confounders is incomplete if measurement is inaccurate.

The other factor that can influence the validity of an association between exposure and outcome is **chance** variation; that is, an association might be observed simply because of chance variation in the distribution of exposure or outcome in the groups being compared. Statistical ‘significance’ testing is aimed at determining whether the difference in outcome between different exposure groups is larger than would be expected to occur purely by chance. This is usually represented by a probability value (*P* (or *p*) value), which is an estimate of the probability that an observed association has occurred by chance (e.g., if a *p* value = 0.001, the probability that the observed association has occurred by chance is estimated to be 1 in 1000). Confidence intervals (CI) are also used to express the possible effects of chance on an estimated statistical measure (e.g. incidence rate or relative risk).

They estimate the interval within which the ‘true’ or population value of the measure falls most of the time (e.g. 95% of the time for a 95% CI and 99% of the time for a 99% CI). In summary, p values and CIs attempt to quantify the degree of uncertainty in a statistic; in this review this is mostly a measure of the association between an exposure and an outcome.

To evaluate the influence of these three factors on the results of the studies included in this review, two complementary approaches were used.

Each included study was categorised according to NHMRC aetiology levels of evidence, as described in Table 4 (Merlin, Weston & Toohar 2009; NHMRC 2008). This hierarchy is included in the FORM grading system (see below) and indicates the degree to which study results are likely to be affected by different types of bias simply because of the way the study has been designed. For example, the results of cross-sectional studies are often affected by recall bias¹⁸, so they are placed at the bottom of the hierarchy. Prospective cohort studies prospectively define how health outcomes are to be measured, and for this reason (among others) they are placed near the top of the hierarchy.

It was determined *a priori* that study quality would be appraised using an adaptation of the checklist by Downs and Black, which has been validated for use across multiple study designs, both experimental and observational controlled studies that assess interventions (Downs & Black 1998). It also contains enough detail to ensure that potential confounders are identified, and that the impact of bias and chance are specifically addressed. However, as no controlled studies were identified during the review, an NHMRC checklist (Box 9.1 in NHMRC 2000)—which was designed to critically appraise aetiology or risk factor studies—was used to assess the studies for influence of bias and confounding (incorporated within Table 7, page 46). The effect of chance on study results was considered when interpreting the statistical analyses presented. Two reviewers critically appraised each of the included studies independently, and a summary judgement was made regarding the methodological quality. When there was a lack of consensus, two senior reviewers were consulted and the study was re-appraised and discussed until a consensus decision was obtained.

¹⁸ Recall bias (or response bias) is a difference between compared groups in the accuracy with which they report past events, or personal behaviour or experience, in response to questions.

Table 4 NHMRC evidence hierarchy: designations of levels of evidence (excerpt)—aetiology research question only

Level	Aetiology ^a
I ^b	A systematic review of level II studies
II	A prospective cohort study
III-1	All or none ^c
III-2	A retrospective cohort study
III-3	A case-control study
IV	A cross-sectional study or case series

^a Definitions of these study designs are provided on pages 7–8 in *How to use the evidence: assessment and application of scientific evidence (NHMRC 2000)* and in its accompanying Glossary.

^b A systematic review will only be assigned a level of evidence as high as the studies it contains, excepting where those studies are of level II evidence. Systematic reviews of level II evidence provide more data than the individual studies, and any meta-analyses will increase the precision of the overall results, reducing the likelihood that the results are affected by chance. Systematic reviews of lower level evidence present results of likely poor internal validity, and thus are rated on the likelihood that the results have been affected by bias rather than whether the systematic review itself is of good quality. Systematic review quality should be assessed separately. A systematic review should consist of at least two studies. In systematic reviews that include different study designs, the overall level of evidence should relate to each individual outcome/result, as different studies (and study designs) might contribute to each different outcome.

^c All or none of the people with the risk factor(s) experience the outcome; and the data arises from an unselected or representative case series that provides an unbiased representation of the prognostic effect. For example, no smallpox develops in the absence of the specific virus; and clear proof of the causal link has come from the disappearance of smallpox after large-scale vaccination.

Sources: Merlin, Weston and Tooher (2009); NHMRC (2008)

Data extraction and synthesis

Relevant data were independently extracted by two reviewers from the included studies, using the data extraction form proposed by the NHMRC but modified to address questions of aetiology (APPENDIX B).

The studies available were limited and heterogeneous and so could not be combined quantitatively in meta-analysis. The review findings were, therefore, synthesised into an overall narrative that addressed each of the review questions, with better quality studies given greater credence in the development of conclusions. This synthesis was informed by the use of the NHMRC Evidence Statement FORM grading system (Hillier et al. 2011; NHMRC 2008). FORM was amended to more clearly indicate that the factor under study was an exposure rather than an intervention, and that the aim was to elucidate the nature of the association between a health outcome and a potential causative factor.

The FORM system allows the evidence to be appraised in terms of methodological rigour (level of evidence and likelihood of bias and confounding)¹⁹, consistency of results, magnitude and precision of the estimates of human health effects, and generalisability and applicability of the findings to the Australian context. On the basis of this appraisal, the body of evidence to address each systematic review question is rated A to D, with an A rating indicating good support and a D rating indicating poor support for the association being tested (see Box 2). Evidence Statement Forms²⁰ were used to synthesise the body of evidence for each systematic review question and to draw a conclusion; these are given in each relevant ‘exposure’ chapter in the ‘Results’ section of this document. As the system is primarily intended for the development of clinical practice guidelines, evidence statements, as opposed to recommendations, were developed for the consideration of the Reference Group.

Box 2 Rating method used to determine degree of support for an association (*adapted from NHMRC FORM system*)

Evidence statement rating	Description
A	Findings from the body of evidence can be trusted.
B	Findings from the body of evidence can be trusted in most situations.
C	The body of evidence has limitations and care should be taken in the interpretation of findings.
D	The body of evidence is weak and findings cannot be trusted.

All of the evidence obtained was categorised and interpreted in the context of epidemiological guidelines developed by Austin Bradford Hill (and modified by Howick, Glasziou and Aronson (2009)) to determine likely cause and effect in the absence of experimental evidence. These Guidelines suggest complementing the available direct evidence of the impact of an exposure or intervention (such as wind turbines) on an outcome (such as adverse health effects) with mechanistic and parallel evidence, in order to determine likely cause and effect (see Table 5). Mechanistic evidence consists of studies that investigate the alleged causal mechanism that connects the exposure to health outcomes. Parallel evidence consists of studies that have similar results and so provide support for a causal hypothesis.

¹⁹ See ‘Critical appraisal of selected evidence’ section above.

²⁰ Adapted from the NHMRC FORM grading system.

For our review of the plausible health effects of wind turbines, the ‘direct evidence’ consisted of the evidence addressing the systematic literature review questions. The background review questions were concerned with the physiological mechanisms by which noise, shadow flicker and EMR might produce adverse health effects (‘mechanistic evidence’), and whether any health effects have been observed from noise, shadow flicker and EMR produced by exposures other than wind turbines (‘parallel evidence’).

Table 5 Conceptual framework to determine causality (modified Bradford Hill Guidelines)

Type of evidence	Guidelines
Direct <i>[evidence assesses impact of exposure on health outcomes]</i>	• Size of health effect not attributable to plausible confounding²¹ • Appropriate temporal proximity—cause precedes health effect and effect occurs after a plausible interval • Appropriate spatial proximity—health effect occurs at the same location as the exposure • Dose-responsiveness—health effect changes according the intensity of the exposure • Reversibility—the health effect possibly produced by an exposure can be reversed by its removal
Mechanistic <i>[evidence investigates mechanisms that are supposed to connect the exposure to the health outcomes]</i>	• Mechanism of action (biological, chemical, mechanical)—can explain the association between the exposure and the purported health effect • Coherence—proposed mechanism of action (causal hypothesis) is consistent with, and is not contradicted by, other current scientific knowledge
Parallel <i>[related studies that have similar results]</i>	• Replicability—the impact of the exposure on health outcomes can be replicated in independent research conducted in exactly the same way as the original research • Similarity—all studies investigating the effect of the exposure on health outcomes report similar results

Source: Howick, Glasziou and Aronson (2009)

Quality assurance

Upon completion, the review document underwent an independent methodological review and was rated as good quality by the National Collaborating Centre for Environmental Health (NCCEH) in Canada.

²¹ Distortion of the association between an exposure and a health outcome by a third factor or variable (confounder) that is related to both.

RESULTS OF SEARCHES

Background review questions (*mechanistic and parallel evidence*)

The questions providing contextual information for this review of the association between wind farms and human health effects do not require a stepped and documented study-selection approach. These questions were intended to elicit general information about the characteristics of wind turbines that might contribute to interpretation of the direct evidence identified through systematic literature review. The background literature obtained was consolidated and summarised; in-text citations were used to support all key statements.

Systematic review questions (*direct evidence*)

The black literature search identified a total of 1778 references; after review of titles and abstracts against the pre-specified eligibility criteria (Box 1, page 33), 30 remained as possibly relevant articles. After full-text retrieval of these 30 articles, 13 were excluded as they were not studies²². A further 10 studies were excluded for the following reasons: 4 considered an exposure that was not relevant for this review (i.e. noise exposure other than living in the vicinity of a wind turbine), 2 included the wrong comparator (response to industrial and transportation noise), 1 used an unsuitable study design (qualitative design), 1 was a duplicate of another included work, 1 did not measure a health outcome and 1 was not written in English (see excluded studies, APPENDIX C). The remaining 7 articles from the black literature search, reporting on 4 studies, met the pre-specified eligibility criteria and so were included in this review (Bakker et al. 2012; Pedersen 2011; Pedersen & Larsman 2008; Pedersen et al. 2009; Pedersen & Persson Waye 2004, 2007; Shepherd et al. 2011). The study selection process is depicted in Figure 1.

The search of grey literature databases identified a total of 1070 references (Figure 1); after exclusion based on type of article, title or abstract, there were 121 articles remaining that were potentially eligible. It was noted that there was considerable overlap of articles retrieved by the grey and black literature searches. Websites, abstracts from conference proceedings, technical documents and theses were assessed against the inclusion criteria. After retrieving 121 potentially relevant documents, 93 were excluded because they were not studies²³. Of the remaining 28 articles, 9 were excluded as they considered non-health outcomes and 8 because they duplicated results from studies previously identified, 2 studies considered populations with an irrelevant exposure, 2 had an unsuitable study design

²² Five articles were commentary/opinion papers, 3 were narrative reviews, 3 discussed wind energy, 1 contained wind turbine background material, and 1 discussed wind farm regulations.

²³ Twenty-six were discussion articles on wind energy, 20 were commentary/opinion papers, 19 were narrative reviews, 14 discussed guidelines or regulations, and 14 provided background on wind turbines.

(qualitative design; case reports), and 1 was excluded as it was not written in English²⁴. Conference abstracts identified as potentially being eligible were found to be either published later in full as technical papers or published in the peer-reviewed literature.

Of those articles that were considered possibly eligible (30 black and 121 grey articles), there were 9 excluded that were common to both the black and grey searches. Six relevant articles were identified in the grey literature database search. Of these, 5 were duplicates of studies included from the black literature search. The remaining article by Nissenbaum, Aramini and Hanning (2011) was updated by a more recent version submitted to the NHMRC (Nissenbaum, Aramini & Hanning 2012) (see below). Hence, no additional articles from the grey literature search were eligible to contribute to the total evidence-base.

In addition to the systematic search, submissions of grey or published literature were provided by the NHMRC to AHTA for consideration in the review (APPENDIX D). These submissions included material from NHMRC files on wind farms and human health, material that had been previously submitted to the NHMRC by stakeholders, and material that was submitted to the NHMRC for consideration in the review during the public call for literature conducted in September 2012 (hereafter referred to collectively as 'the submissions'). Some of the submissions were websites or citations for which the full text needed to be retrieved. Of the 506 submissions, the full text of 5 documents was either not found or not sighted in time for inclusion in this review. Ten submissions were considered to fit the selection criteria determined *a priori* (and were not already identified or included) for this review; 6 of which were subsequently excluded. One of these (Phipps, McCoard & Fisher 2008) reported on preliminary results from a survey on the visual and noise effects of wind turbines; however, on further investigation it was determined that health outcomes were not reported. A study by Nissenbaum, Aramini and Hanning (2012) was identified in the submitted literature which updated an older version identified in the systematic grey literature search (also referred to above). Wang (2011) provided information on the same study as Morris (2012). Harry (2007), Iser (2004) and Pierpont (2009) were case reports and case series, and so were excluded on the advice of the Reference Group (see page 30).

Thus, overall, 4 articles were included in this review from submissions, 3 of which were individual studies (Krogh et al., 2011; Morris 2012; Nissenbaum, Aramini & Hanning 2012), while 1 provided additional data to the study by Bakker et al. (2012) found in the black literature search (van den Berg et al. 2008).

In total, the black, grey and submitted literature yielded 7 studies that were discussed in 11 articles that met the criteria for inclusion in this review (see flowchart, Figure 1).

²⁴ An English translation was identified and the reference was found not to be a study.

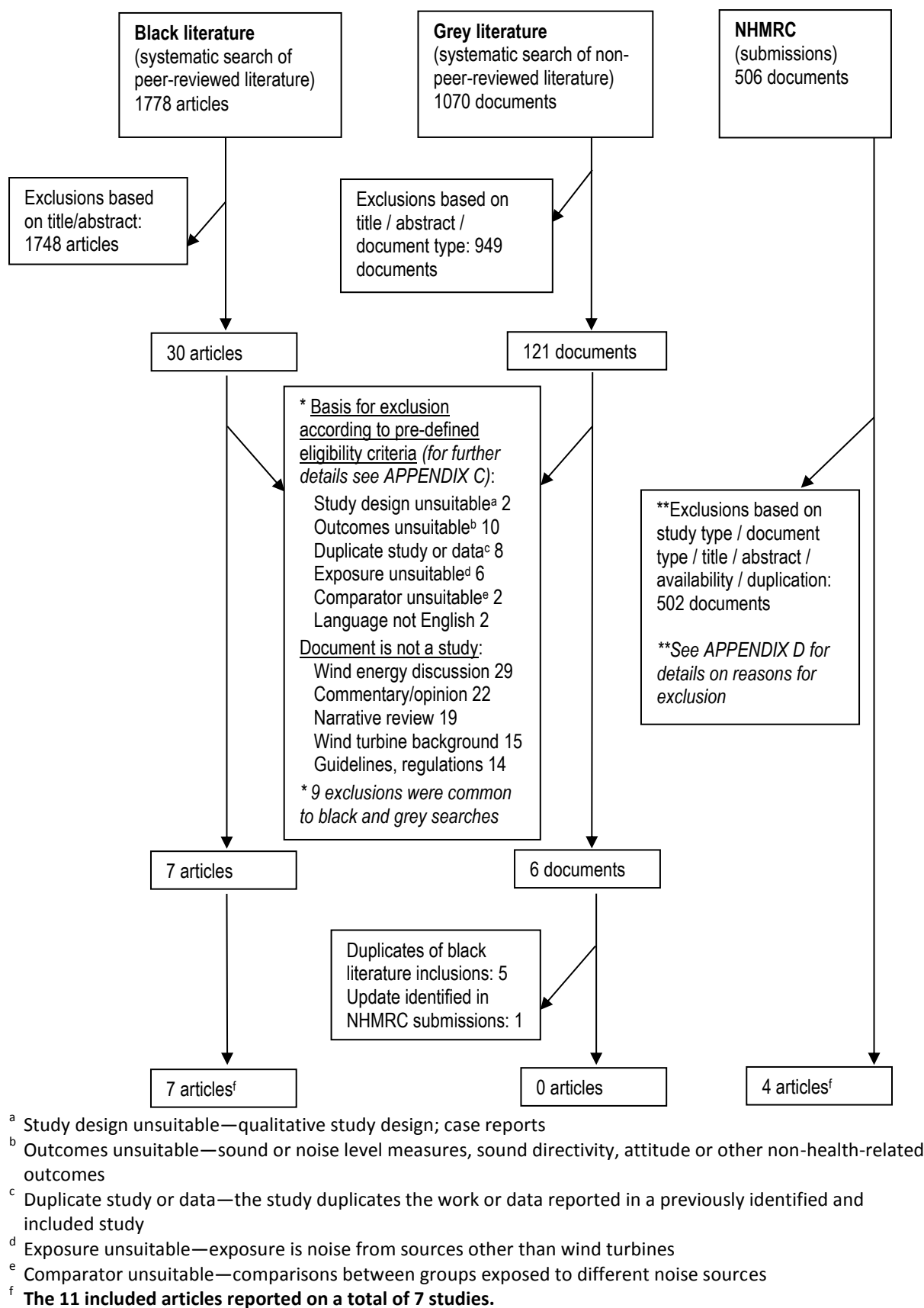


Figure 1 Process of study selection according to eligibility criteria in Box 1

The results of three of the studies (SWE-00, SWE-05, NL-07), which shared aspects of a common protocol, were distributed across seven publications (see Table 6). These and the other studies provide evidence regarding the effects of noise from wind turbines on health or other factors that may relate to health, such as annoyance. In addition to the effects of noise, one study reported results for the effects of shadow flicker on annoyance. No studies were identified that explicitly considered the effects on human health of ‘infrasound and low-frequency noise’ or ‘electromagnetic radiation’ produced by wind turbines.

No other physical emissions associated with adverse health effects were apparent from the literature obtained.

Table 6 Evidence map of literature obtained to answer the systematic review questions

Study identifier	Most comprehensive report	Study location	Articles contributing additional data on the study and/or providing additional analyses or comparisons between studies
NL-07	Bakker et al. (2012)	The Netherlands	Van den Berg et al. (2008) Pedersen et al. (2009) Pedersen (2011)
Krogh et al. (2011)	Krogh et al. (2011)	Ontario, Canada	
Morris (2012)	Morris (2012)	South Australia	
Nissenbaum, Aramini and Hanning (2012)	Nissenbaum, Aramini and Hanning (2012)	Maine, USA	
SWE-00	Pedersen and Persson Waye (2004)	Sweden	Pedersen and Larsman (2008) Pedersen (2011)

SWE-05	Pedersen and Persson Waye (2007)	Sweden	Pedersen and Larsman (2008) Pedersen (2011)
Shepherd et al. (2011)	Shepherd et al. (2011)	New Zealand	

Profiles of each of the 7 included studies, and references to the articles reporting on each, are given in Table 7. In Table 7 attention is given to the domains suggested by the NHMRC for the quality appraisal of aetiologic or risk factor studies, along with assessments of bias, confounding, chance and overall study quality. More detailed information on outcome measurement and the results obtained in these studies is given in each of the 'emission' chapters to follow. Additional information on each of the articles is provided in APPENDIX B.

Table 7 Profile of the studies included to address the systematic review questions (*critical appraisal adapted from NHMRC 2000, Box 9.1*)

Further details on the included studies and the study results are given in the chapters that are specific to the different exposures.

Study identification	The Netherlands NL-07 Bakker et al. (2012)	Ontario, Canada Krogh et al. (2011)	Australia Morris (2012)	Maine, USA Nissenbaum, Aramini and Hanning (2012)	Sweden SWE-00 Pedersen and Persson Waye (2004)	Sweden SWE-05 Pedersen and Persson Waye (2007)	New Zealand Shepherd et al. (2011)
Study type	Cross-sectional self-report questionnaire N=725	Cross-sectional self-report questionnaire N=109	Cross-sectional self-report questionnaire N=93 households	Cross-sectional self-report questionnaire N=79	Cross-sectional self-report questionnaire N=351	Cross-sectional self-report questionnaire N=754	Cross-sectional self-report questionnaire N=198
Articles contributing additional data^a	Van den Berg et al. (2008) Pedersen et al. (2009) Pedersen (2011)				Pedersen and Larsman (2008) Pedersen (2011)	(Pedersen and Larsman (2008) Pedersen (2011)	
Characteristics of population and study setting	Dutch population living in rural and urban settings within 2.5 km of wind turbines Mean age = 51 years	Residents in 5 project areas in Ontario, Canada where adverse health effects had been anecdotally reported	Households within 10 km of Waterloo wind farm, South Australia No population characteristics reported	Residents of Mars Hill and Vinalhaven Maine, USA – locations of wind farms Mean age of ‘far’ group older than	Residents of southern Sweden living 150–1199 m from wind turbines Mean age = 48±14 years	Swedish population residing in wind turbine areas with differing terrain and levels of urbanisation	Residents of Makara Valley, New Zealand living <2km or ≥8 km from a wind turbine Age distribution by

Study identification	The Netherlands NL-07 Bakker et al. (2012)	Ontario, Canada Krogh et al. (2011)	Australia Morris (2012)	Maine, USA Nissenbaum, Aramini and Hanning (2012)	Sweden SWE-00 Pedersen and Persson Waye (2004)	Sweden SWE-05 Pedersen and Persson Waye (2007)	New Zealand Shepherd et al. (2011)
	% male = 51	Fluency in English required Mean age = 52 years % male = 48		'near' group % male 'near' group = 58 % male 'far' group = 44	% male = 42	Mean proximity to turbines = 780±233 m Mean age = 51±15 years % male = 44	group given in APPENDIX B % male 'near' group = 41 % male 'far' group = 41
Exposure considered	Modelled sound pressure level outside residences near wind turbines in dB(A) Averaged over time with 8 m/s downwind; range = 21–54 dB(A), mean = 35 dB(A) Grouped into five dB(A) categories:	Exposure to wind turbines (noise levels not reported) All residences located within 2.4 km of wind turbines Distance from turbine: 350–490 m, 24%; 55–673 m, 23%;	Exposure to wind turbines (noise levels not reported) Residences located within 10 km of wind turbines of wind turbines; subgroup within 0–5 km	Estimated sound levels due to wind turbines - derived from a four-season study conducted 2 years previously Measurements were taken at specific distances and expressed as $LA_{eq, 1\text{ hour}}$	Modelled sound pressure levels in dB(A) outside residences located near wind turbines Grouped into six dB(A) categories: <30, 30–32.5, 32.5–35, 35–37.5, 37.5–40 and >40 dB(A)	Modelled sound pressure levels in dB(A) estimated outside residences located near wind turbines Based on downwind conditions (±45°) with wind speed 8 m/s at height 10 m	Exposure to wind turbines (noise levels estimated 24–54 dB(A)) Exposed participants in dwellings (n=56 homes) <2 km from the nearest wind turbine; non-exposed controls resided (n=250 homes) ≥8 km

Study identification	The Netherlands NL-07 Bakker et al. (2012)	Ontario, Canada Krogh et al. (2011)	Australia Morris (2012)	Maine, USA Nissenbaum, Aramini and Hanning (2012)	Sweden SWE-00 Pedersen and Persson Waye (2004)	Sweden SWE-05 Pedersen and Persson Waye (2007)	New Zealand Shepherd et al. (2011)
	<30, 30–35, 36–40, 41–45, >45 dB(A)	700–808 m, 30%; 900–2400 m, 17%		Range = 32–52 dB Two exposure groups: ‘near’ within 1.5 km of turbines; ‘far’ group 3–7 km from turbines		Respondents’ dwellings grouped in five dB(A) categories: <32.5, 32.5–35.0, 35.0–37.5, 37.5–40 and >40 dB(A)	from a turbine
Effects or outcomes considered	Bakker et al. 2012 Sleep disturbance, psychological distress scores (GHQ-12), annoyance outside, annoyance inside Van den Berg et al. (2008): (a) psychological distress (GHQ-12 score and stress score); (b) any	Self-reported adverse effects—altered quality of life, altered health, disturbed sleep, excessive tiredness, tinnitus, stress, headaches, migraines, hearing problems, heart palpitations, anxiety, depression, distress, and whether they had	Annoyed by flickering, disturbed sleep, sleep quality, ear pain/pressure, tinnitus, headache, nausea, high blood pressure	Sleep quality (ESS and PSQI scales); physical and mental health (SF-36v2 scale)	Perception of noise and annoyance due to turbine sound Pedersen & Larsman (2008): Influence of noise level, visual attitude and general attitude on annoyance Pedersen (2011): Annoyance, sleep	Perception of noise; annoyance with noise Pedersen and Larsman (2008): Influence of noise level, visual attitude and general attitude on annoyance Pedersen (2011): Annoyance, sleep interruption,	QoL as per WHO quality of life scale (brief version)—WHOQOL-BREF—which includes self-reported general health Additional outcomes on amenity, annoyance, noise sensitivity, neighbourhood problems

Study identification	The Netherlands NL-07 Bakker et al. (2012)	Ontario, Canada Krogh et al. (2011)	Australia Morris (2012)	Maine, USA Nissenbaum, Aramini and Hanning (2012)	Sweden SWE-00 Pedersen and Persson Waye (2004)	Sweden SWE-05 Pedersen and Persson Waye (2007)	New Zealand Shepherd et al. (2011)
	chronic disease, diabetes, high blood pressure, tinnitus, hearing impairment, cardiovascular disease, migraine and sleep quality; (c) annoyance due to visual factors and vibration Pedersen et al. (2009): Response (do not notice/annoyance) to wind turbine noise outdoors and indoors, and attitude to wind turbines Pedersen 2011:	approached a doctor			interruption, chronic disease, diabetes, high blood pressure, cardiovascular disease, tinnitus, impaired hearing, headache, undue tiredness, tense and stressed, irritable	chronic disease, diabetes, high blood pressure, cardiovascular disease, tinnitus, impaired hearing, headache, undue tiredness, tense and stressed, irritable	

Study identification	The Netherlands NL-07 Bakker et al. (2012)	Ontario, Canada Krogh et al. (2011)	Australia Morris (2012)	Maine, USA Nissenbaum, Aramini and Hanning (2012)	Sweden SWE-00 Pedersen and Persson Waye (2004)	Sweden SWE-05 Pedersen and Persson Waye (2007)	New Zealand Shepherd et al. (2011)
	Annoyance, sleep interruption, chronic disease, diabetes, high blood pressure, cardiovascular disease, tinnitus, impaired hearing, headache, undue tiredness, tense and stressed, irritable						
Evaluation criteria							
Are the study participants well defined in terms of time, place and personal characteristics? [exposure]	Partly—in terms of place (<i>and in personal characteristics in van den Berg et al. 2008, see APPENDIX B</i>) <u>Personal</u>	Partly—in terms of place <u>Personal characteristics:</u> Age and gender only personal characteristics	Partly—in terms of place <u>Personal characteristics:</u> None reported <u>Place:</u> All residents	Partly—in terms of place <u>Personal characteristics:</u> Age and gender only personal characteristics	Partly—in terms of personal characteristics and place <u>Personal characteristics:</u> Age, gender, residence,	Partly—in terms of personal characteristics and place <u>Personal characteristics:</u> Age, gender, residence type and	Partly—in terms of personal characteristics and place <u>Personal characteristics:</u> Age, gender, education,

Study identification	The Netherlands NL-07 Bakker et al. (2012)	Ontario, Canada Krogh et al. (2011)	Australia Morris (2012)	Maine, USA Nissenbaum, Aramini and Hanning (2012)	Sweden SWE-00 Pedersen and Persson Waye (2004)	Sweden SWE-05 Pedersen and Persson Waye (2007)	New Zealand Shepherd et al. (2011)
misclassification]	<u>characteristics:</u> Age not reported by exposure status (only the overall mean provided), gender and location of residence described <u>Place:</u> All residents lived within 2.5 km of wind turbines. Noise exposure was modelled <u>Time:</u> This is a cross-sectional study with self-reported outcome measures; therefore, it cannot be	described <u>Place:</u> All residents live within 2.4 km of wind turbines Distance as a proxy for noise exposure <u>Time:</u> This is a cross-sectional study with self-reported outcome measures; therefore, it cannot be determined objectively whether wind farm exposure preceded the reported outcome(s)	live within 10 km of wind turbines Distance as a proxy for noise exposure <u>Time:</u> This is a cross-sectional study with self-reported outcome measures; therefore, it cannot be determined objectively whether wind farm exposure preceded the reported outcome(s)	described <u>Place:</u> Two exposures: 'near' within 1.5 km of turbines; 'far' group 3–7 km from turbines. Noise exposure was estimated from previous research at the site <u>Time:</u> This is a cross-sectional study with self-reported outcome measures; therefore, it cannot be determined objectively whether wind	occupation, noise sensitivity, attitude to turbines and long-term illness described <u>Place:</u> All residents lived 150–1199 m from wind turbines. Noise exposure was modelled <u>Time:</u> This is a cross-sectional study with self-reported outcome measures; therefore, it cannot be determined objectively	duration, occupation, noise sensitivity and chronic disease status described <u>Place:</u> Mean proximity to turbines = 780±233 m Noise exposure was modelled <u>Time:</u> This is a cross-sectional study with self-reported outcome measures; therefore, it cannot be determined objectively whether wind	employment status, noise sensitivity and current illness described <u>Place:</u> Two exposure groups: 'exposed' group within 2 km of turbines; control group ≥8 km from turbines Noise exposure was estimated from previous research at the site <u>Time:</u> This is a cross-sectional study with self-reported outcome

Study identification	The Netherlands NL-07 Bakker et al. (2012)	Ontario, Canada Krogh et al. (2011)	Australia Morris (2012)	Maine, USA Nissenbaum, Aramini and Hanning (2012)	Sweden SWE-00 Pedersen and Persson Waye (2004)	Sweden SWE-05 Pedersen and Persson Waye (2007)	New Zealand Shepherd et al. (2011)
	determined objectively whether wind farm exposure preceded reported outcome(s)			farm exposure preceded the reported outcome(s).	whether wind farm exposure preceded the reported outcome(s)	farm exposure preceded the reported outcome(s)	measures; therefore, it cannot be determined objectively whether wind farm exposure preceded reported outcome(s)
What percentage of individuals or clusters refused to participate? [selection bias]	63% of those who received a questionnaire did not complete and return it Sampling area determined by distance from wind turbines High non-participation rate indicates a high	Not reported what proportion did not complete and return questionnaire Sampling area was chosen because adverse health effects had been reported there Multiple adults from same	60% of questionnaires delivered to households were not returned Sampling area determined by distance from wind turbines High non-participation rate indicates a high	Of those who received a questionnaire: 'Near' group = 42% did not complete and return it 'Far' group = not reported what proportion did not complete and return it Sampling area	32% of those who received a questionnaire did not complete and return it Individuals selected in pseudo-random method (one subject in each household in area, with birth date closest to 20 May)	42% of those who received a questionnaire did not complete and return it Sampling area determined by distance from wind turbines and type of terrain Moderate non-participation rate	Of those who received a questionnaire: 'Exposed' group = 66% did not complete and return it Control group = 68% did not complete and return it Sampling area

Study identification	The Netherlands NL-07 Bakker et al. (2012)	Ontario, Canada Krogh et al. (2011)	Australia Morris (2012)	Maine, USA Nissenbaum, Aramini and Hanning (2012)	Sweden SWE-00 Pedersen and Persson Waye (2004)	Sweden SWE-05 Pedersen and Persson Waye (2007)	New Zealand Shepherd et al. (2011)
	probability of selection bias which may vary depending on wind turbine exposure. 200/1223 non-responders were randomly selected for a subsequent analysis, and in the 95 'responding non-responders' there were no statistically significant differences in annoyance levels in comparison with those who responded to the primary questionnaire.	household were able to respond, so if household size differs by distance from a wind turbine this would bias the results.	probability of selection bias which may vary depending on wind turbine exposure.	determined by distance from wind turbines Potentially different non-participation rate in the two groups. Moderate non-participation rate in "exposed" group.	Sampling area determined by distance from nearest wind turbine	indicates a probability of selection bias which may vary depending on wind turbine exposure.	determined by distance from wind turbines High non-participation rate indicates a high probability of selection bias, so characteristics of sample may vary depending on wind turbine exposure.

Study identification	The Netherlands NL-07 Bakker et al. (2012)	Ontario, Canada Krogh et al. (2011)	Australia Morris (2012)	Maine, USA Nissenbaum, Aramini and Hanning (2012)	Sweden SWE-00 Pedersen and Persson Waye (2004)	Sweden SWE-05 Pedersen and Persson Waye (2007)	New Zealand Shepherd et al. (2011)
	Pedersen et al. (2009): 63% Non-participation rate was 56-61% in the two lowest exposure categories and 67-68% in the three highest categories.						
Are outcomes measured in a standard, valid and reliable way? [outcome misclassification]	Partly—GHQ-12 used for some outcomes GHQ-12 is a valid measure of psychiatric ill health Remaining components of	No The survey form designed by Harry (2007) was reproduced and used for this survey Health outcomes were self-reported	No A purpose-designed form was used for this survey Health outcomes were self-reported	Partly—PSQI, ESS, SF-36v2 used PSQI, ESS, SF-36v2 considered to be standardised and valid measures Other parts of the questionnaire were purpose-	No Assumed to be a purpose-designed survey created by the study authors. Health outcomes were self-reported.	No Assumed to be a purpose-designed survey created by the study authors. Health outcomes were self-reported.	Partly—WHOQOL-BREF used Used validated WHO quality of life scale (brief version) (WHOQOL-BREF) with following components: physical,

Study identification	The Netherlands NL-07 Bakker et al. (2012)	Ontario, Canada Krogh et al. (2011)	Australia Morris (2012)	Maine, USA Nissenbaum, Aramini and Hanning (2012)	Sweden SWE-00 Pedersen and Persson Waye (2004)	Sweden SWE-05 Pedersen and Persson Waye (2007)	New Zealand Shepherd et al. (2011)
	study questionnaire were based on tool used in SWE-00 and SWE-05, excluding questions on coping strategies and with new questions on health and environment. Health outcomes were self-reported			designed for the study. Health outcomes were self-reported.			psychological, social and environmental Authors added additional items which appear to be purpose-designed
What percentages of individuals or clusters recruited into the study are not included in the analysis (i.e. loss to follow-up)?	None	Four responders who were under 18 years of age, and 2 who lived further from the turbines (5 km) compared with the	None	None	None	None	None

Study identification	The Netherlands NL-07 Bakker et al. (2012)	Ontario, Canada Krogh et al. (2011)	Australia Morris (2012)	Maine, USA Nissenbaum, Aramini and Hanning (2012)	Sweden SWE-00 Pedersen and Persson Waye (2004)	Sweden SWE-05 Pedersen and Persson Waye (2007)	New Zealand Shepherd et al. (2011)
		others, were not included in the analysis					
Recall bias?	Uncertain Study intent was masked for respondents—unknown how effective this was	Likely Intent of survey not masked – “affected” people were encouraged to participate	Likely Intent of survey not masked	Likely Intent of survey not masked	Uncertain Study intent was masked for respondents—unknown how effective this was	Uncertain Study intent was masked for respondents—unknown how effective this was	Uncertain Study intent was masked for respondents—unknown how effective this was
Confounding? (other factors that could affect the outcomes)	<u>Analyses adjusted for:</u> Age, gender, employment, terrain, urbanisation, economic benefit from turbines, background noise, noise sensitivity, attitude to turbines and	<u>Analyses adjusted for:</u> Gender in some analyses <u>Other plausible confounders not addressed:</u> Economic factors, age, chronic disease and risk factors for chronic	<u>Analyses adjusted for:</u> Nil <u>Other plausible confounders not addressed:</u> Economic factors, age, gender, chronic disease and risk factors for chronic disease,	<u>Analyses adjusted for:</u> Age, gender, site, and household clustering <u>Other plausible confounders not addressed:</u> Economic factors, chronic disease and risk factors for	<u>Analyses adjusted for:</u> Age, gender, noise sensitivity, visual impact, attitude to turbines in some analyses <u>Other plausible confounders not addressed:</u> Economic factors,	<u>Analyses adjusted for:</u> Age, gender, employment, housing, residence duration, terrain, urbanisation, background noise, noise sensitivity, visual impact, attitude to turbines	<u>Analyses adjusted for:</u> Length of residence (and participants selected from geographic and socio-economic matched areas) <u>Other plausible confounders not</u>

Study identification	The Netherlands NL-07 Bakker et al. (2012)	Ontario, Canada Krogh et al. (2011)	Australia Morris (2012)	Maine, USA Nissenbaum, Aramini and Hanning (2012)	Sweden SWE-00 Pedersen and Persson Waye (2004)	Sweden SWE-05 Pedersen and Persson Waye (2007)	New Zealand Shepherd et al. (2011)
	turbine visibility (covariates varied between analyses) <u>Other plausible confounders not addressed:</u> Socioeconomic factors (<i>was addressed in van den Berg et al 2008</i>), chronic disease and risk factors for chronic disease, and occupation	disease, occupation, education, employment, terrain, urbanisation, background noise, and turbine visibility	occupation, education, employment, terrain, urbanisation, background noise, and turbine visibility	chronic disease, occupation, education, employment, terrain, urbanisation, background noise, and turbine visibility	chronic disease and risk factors for chronic disease, occupation, education, employment, terrain, urbanisation, background noise	(covariates varied between analyses) <u>Other plausible confounders not addressed:</u> Economic factors, chronic disease and risk factors for chronic disease, occupation, education.	<u>addressed:</u> Age, chronic disease and risk factors for chronic disease, occupation, employment, education, background noise, and turbine visibility
Chance?	No evidence of adjustment of p-values for multiple statistical tests	No evidence of adjustment of p-values for multiple statistical tests or for some clustering of participants in	No formal statistical tests for chance association were conducted	No evidence of adjustment of p-values for multiple statistical tests	Adjustment of p-values for multiple statistical tests using Bonferroni's method	No evidence of adjustment of p-values for multiple statistical tests	Adjustment of p-values for multiple statistical tests using Bonferroni's method 5 cases excluded

Study identification	The Netherlands NL-07 Bakker et al. (2012)	Ontario, Canada Krogh et al. (2011)	Australia Morris (2012)	Maine, USA Nissenbaum, Aramini and Hanning (2012)	Sweden SWE-00 Pedersen and Persson Waye (2004)	Sweden SWE-05 Pedersen and Persson Waye (2007)	New Zealand Shepherd et al. (2011)
		households					from comparator group due to being multivariate outliers
Overall quality of the study to determine whether wind farms cause adverse health effects?	Poor High risk of: • exposure misclassification • selection bias • significant associations due to chance Potential for: • outcome misclassification • recall bias • confounding	Poor High risk of: • exposure misclassification • outcome misclassification • recall bias • selection bias • confounding • significant associations due to chance	Poor High risk of: • exposure misclassification • selection bias • outcome misclassification • recall bias • confounding	Poor High risk of: • exposure misclassification • recall bias • selection bias • confounding • significant associations due to chance Potential for: • outcome misclassification	Poor High risk of: • exposure misclassification • outcome misclassification • confounding Potential for: • recall bias	Poor High risk of: • exposure misclassification • selection bias • outcome misclassification • significant associations due to chance Potential for: • recall bias • confounding	Poor High risk of: • exposure misclassification • selection bias • confounding Potential for: • outcome misclassification • recall bias

Abbreviations: dB = decibels; dB(A) = A-weighted sound pressure (decibels); $LA_{eq, 1\text{ hour}}$ = A-weighted noise level over 1 hour; m/s = metres per second as a measurement of wind speed; GHQ-12 = General Health Questionnaire, version 12; NA = not applicable; ESS = Epworth Sleepiness Scale; PSQI = Pittsburgh Sleep Quality Index; SF-36v2 = Short Form (36) Health Survey, version 2; NR = not reported; QoL = quality of life; WHO = World Health Organization

^a Where additional articles contribute further information, the details are included in the column for the associated study.

NOISE

BQ2. BY WHAT SPECIFIC PHYSICAL EMISSIONS MIGHT WIND TURBINES CAUSE ADVERSE HEALTH EFFECTS?

Noise is defined as an unwanted sound or an unwanted combination of sounds. Therefore, what can be considered 'noise' will vary between individuals depending on factors such as the complex temporal pattern and intensity of the sound, cultural attitudes, timing and other circumstances (e.g. a Beethoven symphony may be music at dinner time but noise in the middle of the night if it disrupts sleep).

Sound is an energy form that travels from a source in the form of waves or pressure fluctuations transmitted through a medium and received by a receiver (e.g. human ear). Sound is perceived and recognised by its loudness (pressure) and pitch (frequency²⁵). The general range for human hearing for young adults is between 20 Hz and 20 kHz, with a declining upper limit as age increases (Berglund, Hassmen & Job 1996). Human sound perception is less sensitive to lower frequency (low pitch) and higher frequency (high pitch) sounds. It is easiest for the human ear to recognise sounds in the middle of the audible spectrum (1–4 kHz) (Roberts & Roberts 2009).

The following sound thresholds have been suggested (Hawkins 2012; Thorne 2011):

- Infrasound, <20 Hz (normally inaudible)
- Low-frequency, 20–200 Hz, although the upper limit can vary (Leventhall 2006; O'Neal, Hellweg & Lampeter 2011)
- Mid-frequency, 200–2000 Hz
- High-frequency, 2–20 kHz.

The decibel (dB) is an indicator of loudness (amplitude) calculated as the logarithmic ratio of sound pressure level (SPL)²⁶ to a reference level (Roberts & Roberts 2009). Sound pressure is a property of sound *at a given observer location* and can be measured at that specific point by a single microphone (Rogers, Manwell and Wright 2006).

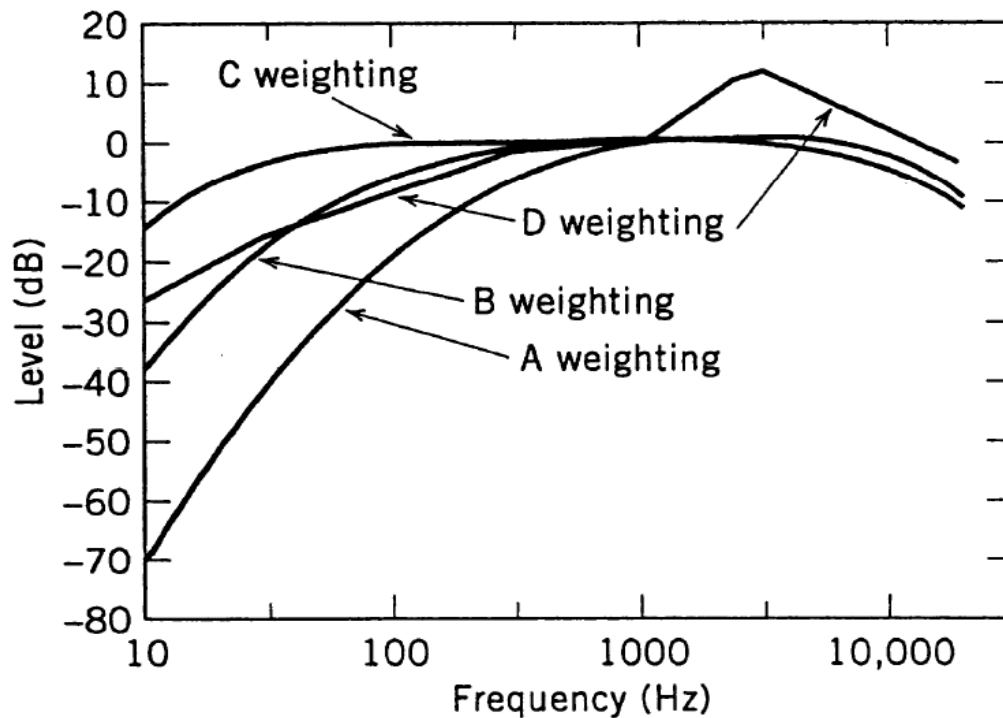
Various filters²⁷ can be used to weight sound pressure measurements as a function of frequency to align them with human sensitivity. The human ear simultaneously receives sound at many frequencies and at different amplitudes. The audibility of the sound varies significantly with the frequency of the sound it is receiving, in addition to the SPL of that sound. At low SPLs, low

²⁵ Frequency is the number of sound waves/cycles passing a given point per second and is measured in cycles per second (cps), also called hertz (Hz).

²⁶ The sound pressure level can be calculated by using the formula $SPL = 10\log_{10}[p^2/p_{ref}^2]$ where p_{ref} is the reference pressure or 'zero' reference for airborne sound (20×10^{-6} pascals)

²⁷ A filter is a device that modifies a sound signal by attenuating some of its frequency components (Jacobsen et al. 2011)

frequencies are less audible than medium frequencies (Jacobsen et al. 2011). The standardised frequency weighting filters are depicted in Figure 2.

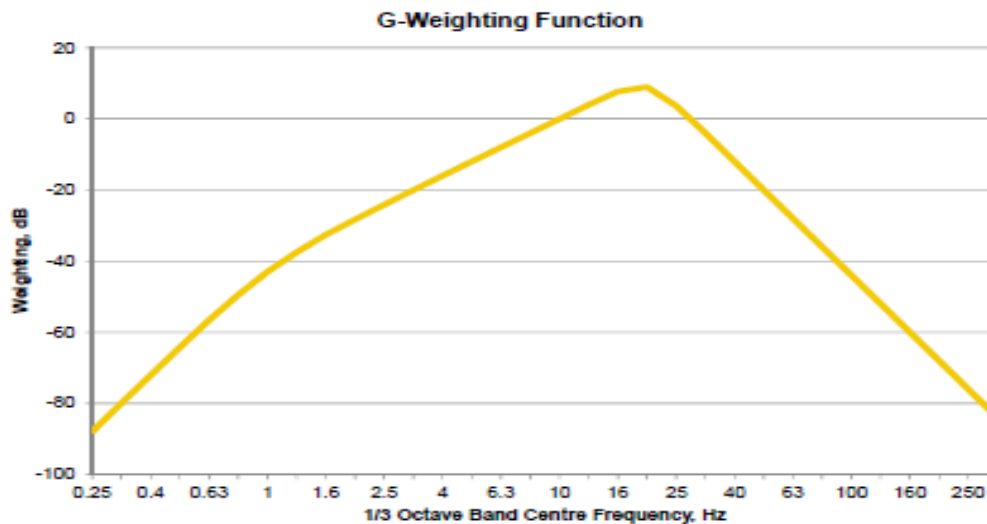


Source: Figure 1.3.7, Jacobsen et al. (2011)

Figure 2 Standardised frequency weighting curves

The A-weighted SPL is the most widely used single-value measure of sound. A-weighted measurements are common because they generally align with the subjective response to noise. However, the A-weighted filter is 'less sensitive' to very-high- and very-low-frequency sound. The C-weighted filter is essentially 'flat' in the audible frequency range, but is 'more sensitive' in the low-frequency range than the A-weighted filter. Therefore, a large difference between the A-weighted level and the C-weighted level is a clear indication of prominent content of low-frequency noise (Jacobsen et al. 2011). B-weighted and D-weighted filters are not often used.

The G-weighting function is used to quantify sound that has a significant portion of its energy in the infrasonic range. The function weights noise levels between 0.25 Hz and 315 Hz to reflect human perception of infrasonic noise levels (Verrotti et al. 2005). Figure 3 (reproduced from Evans, Cooper & Lenchine (2013)) depicts the G-weighting function across this frequency range. The weighting shown is applied directly to the unweighted noise levels. The perception of sound in the infrasonic range is greatest at 20 Hz, with a reduction as the frequency decreases.



Source: Figure 2, Evans, Cooper and Lenchine (2013)

Figure 3 G-weighting function across 1/3 octave band frequency (Hz)

Sound perception and distance

Measurements of sound from a particular source vary according to the distance from the source. Sound pressure decreases with distance (r) from a point source in an inverse ($1/r$) relationship, and sound intensity²⁸ decreases in a relationship of $1/r^2$ according to the *inverse distance law* (Jacobsen et al. 2011). In effect, when distance is doubled, the sound pressure value is reduced to one-half of its initial value (50%) and the sound intensity value is reduced to one-quarter of its initial value (25%). Because of the decrease in sound pressure with distance, it is important to consider distance from the source when assessing the impact of sound or noise.

Due to the predictable decrease in sound pressure with increasing distance from a source, it is possible to use distance as a proxy for SPL measures. It should be noted, however, that, in addition to distance from the source, wind direction, terrain, temperature and time of day can affect sound levels. Another characteristic of sound is that longer wavelengths (low-frequency) travel further through most media (e.g. air, water) than shorter wavelengths, and generally show less attenuation than shorter wavelengths when travelling through solid media such as walls and windows (Persson Waye 2004). This characteristic is relevant to the consideration of sound produced by wind turbines, given that residences are usually at a distance from turbines.

²⁸ The sound intensity can be defined as the sound power per unit area at a point on a radiating sound wave. Sound intensity is not the same physical quantity as sound pressure. Hearing is directly sensitive to sound pressure, which is related to sound intensity (Jacobsen et al. 2011).

Infrasound and low-frequency noise (ILFN)

The definitions of infrasound and low-frequency noise (ILFN), and what can be termed as audible and inaudible, are summarised below (O'Neal, Hellweg & Lampeter 2011; Watanabe & Møller 1990; Berglund, Hassmen & Job 1996):

- There is no clear definition of the upper limit of low-frequency sound. The definitions vary and can range from 100 Hz to 250 Hz.
- Sound <20 Hz is generally termed infrasound and is not considered in the low-frequency range, on the basis that infrasound is considered inaudible in normal environments. However, the hearing threshold is dependent on the frequency and level of the sound and frequencies well below 20 Hz can be audible if the amplitude of the SPL is high enough. In addition there is inter-individual variation in hearing thresholds.
- For sounds to be audible at frequencies <20 Hz, they need to have an amplitude of >80 dB. For example, at a frequency of 5 Hz the amplitude would need to be higher than 103 dB.

Mechanisms by which noise might affect health

Noise has the potential to affect health through stress and hearing loss.

Biological studies of the impact of noise that is sufficiently loud to cause hearing loss are, in general, well documented in the scientific literature (Azizi 2010). Noise-induced pathology as a result of higher metabolic activity was originally proposed in the 1970s (Lim & Melnick 1971). It was suggested that noise-induced hearing loss (NIHL) might be the consequence of oxidative stress such that there is an initial increase in the rate of cochlear blood flow, followed by capillary vasoconstriction and an abrupt decrease in cochlear circulation, leading to a subsequent increase in metabolic activity and enhanced production of free radicals (Seidman & Standring 2010). Free radicals, or Reactive Oxygen Species (so called when they are produced *in vivo* as a by-product of mitochondrial respiration), have the potential to lead to cell death and cause irreversible damage to hearing structures when present in excessive amounts. NIHL mainly occurs between 500 and 8000 Hz, with legal deafness assessed at 4000 Hz (Alves-Pereira & Castelo Branco 2007).

Stress is considered another mechanism by which noise can impact on human health (Babisch 2002). However, because of the individual variation in response to stressors, adaptability to stress, and the associated impact of other plausible factors (confounders) that may affect health, there is little consensus as to how noise-related stress affects health. Three key features of the stress-health process (cortisol, suppression of the immune system and psychological distress) have been measured in noise research.

Research suggests that there is no relationship between level of noise and serum cortisol level. This could be because a high noise level may act directly as a stressor, whereas low levels may only affect cortisol secretion if the noise is considered disturbing by the individual. It is also hypothesised that high cortisol concentrations may cause partial destruction of cortisol receptors in the brain, which in turn may be responsible for chronic elevation of cortisol, with long-term side effects of arteriosclerosis and immunosuppression (Prasher 2009; van Kamp et al. 2007). However,

these hypothesised long-term effects could equally be a consequence of other exposures (confounders) in the same noise-producing environment, e.g. toxic substance exposure, work demands and air pollution (Selander et al. 2009; Davis & Kamp 2012; Selander et al. 2013).

Where stress effects are present, they may be dependent on the level of annoyance induced by the noise (Laszlo et al. 2012). For example, exposure to aircraft noise only increases the risk of hypertension in those who are annoyed by the noise (Eriksson et al. 2007). Babisch (2002) states that *“prolonged exposure to the same noise can lead to habituation and negative effects on performance may then disappear”*.

In addition, Babisch (2002) notes that *“individuals perform better when the acute exposure matches their normal exposure. This suggests that individuals regularly exposed to noise will do worse in quiet than those from quiet environments, whereas the reverse will occur if the two groups are tested in noise”*.

Stress may also be induced by the degree of sleep disruption associated with noise. The adverse effects on sleep appear to be larger for unpredictable noise and rapidly changing noise, when compared with a predictable constant noise. The level of noise is not a predictor of a stress reaction during sleep. Stress reactions are instead associated with the meaning of the noise to the individual (Prasher 2009). Recent work has shown that individuals who generate more sleep spindles (a thalamocortical rhythm manifested on the EEG as a brief 11–15 Hz oscillation) during a quiet night of sleep exhibit higher tolerance for noise during a subsequent, noisy night of sleep. This provides strong support to the concept that there is inter-individual variation in resilience to sleep-disruptive stimuli (Dang-Vu et al. 2010).

The studies mentioned above examined sound levels in the audible frequency range. Like most noise sources, wind turbines emit multiple frequencies of sound, both infrasonic and audible. The frequency range of sound emitted from wind turbines is discussed more comprehensively below but, given that most residences are sited at a distance from wind turbines, the most relevant sound exposure is ILFN. While ILFN may not cause auditory damage, other biological damage resulting from heavy exposure to ILFN has been suggested, although it is an area of controversy (Alves-Periera et al. 2007; Leventhall 2009). The evidence for whether ILFN also produces stress effects is addressed in Background Question 4 (see page 110).

BQ3. FOR EACH EMISSION, WHAT IS THE LEVEL OF NOISE EXPOSURE FROM A WIND TURBINE AND HOW DOES IT VARY BY DISTANCE AND CHARACTERISTICS OF THE TERRAIN SEPARATING A WIND TURBINE FROM POTENTIALLY EXPOSED PEOPLE?

Since concerns have been raised about human exposure to ILFN from wind turbines, it is important to determine the likely level of exposure (dose) experienced by people living in the vicinity of wind farms.

Sound from wind turbines

Sound from wind turbines is described in the literature as either mechanical or aerodynamic (Ellenbogen et al. 2012; Roberts & Roberts 2009). These sound types are also characterised as tonal²⁹ or broadband³⁰, constant amplitude or amplitude modulated, and audible or inaudible/infrasonic (Ellenbogen et al. 2012). Turbines with downwind rotors should be distinguished from turbines with upwind rotors—early wind turbines had downwind rotors, which emitted higher levels of infrasound than turbines with upwind rotors (Rogers, Manwell and Wright 2006). Modern wind farms very rarely use the downwind design.

Mechanical sound is produced mainly from moving rotational and electrical components, including the gearbox, generator, yaw drives, cooling fans and auxiliary of the turbine. Noise from a 1500-kW turbine, with a generator speed ranging from 1100 to 1800 revolutions per minute (rpm), contains a sound tone frequency between 20 and 30 Hz (Ellenbogen et al. 2012).

Aerodynamic noise is the major component of noise from modern wind turbines, given that improvements in wind turbine design and manufacture have reduced mechanical noise to a level that is below that of aerodynamic noise (Pedersen & Persson Waye 2004, 2007; van den Berg 2004). A key source of aerodynamic sound from modern wind turbines is the trailing edge noise that originates from air flow around the components of the wind turbine (blades and tower), producing a ‘whooshing’ sound in the 500–1000 Hz range (Hau 2008; Roberts & Roberts 2009). This is often described as amplitude (or aerodynamic) modulation, meaning that the sound can vary due to atmospheric effects and directional propagation effects (see ‘Measurement of sound from wind turbines’ section below) (van den Berg 2004). Table 8 summarises the different sources of aerodynamic sound from a wind turbine as reproduced by Ellenbogen et al. (2012) from Wagner, Bareiss and Guidati (1996).

²⁹ Sound at discrete frequencies.

³⁰ Characterised by a continuous distribution of sound pressure with frequencies >100 Hz.

Table 8 Sources of aerodynamic sound from a wind turbine

Noise type	Mechanism	Characteristic
Trailing-edge noise	Interaction of boundary layer turbulence with blade trailing edge	Broadband, main source of high-frequency noise (770 Hz < f < 2 kHz)
Tip noise	Interaction of tip turbulence with blade tip surface	Broadband
Stall, separation noise	Interaction of turbulence with blade surface	Broadband
Laminar boundary layer noise	Non-linear boundary layer instabilities interacting with the blade surface	Tonal
Blunt trailing-edge noise	Vortex shedding at blunt trailing edge	Tonal
Noise from flow over holes, slits and intrusions	Unsteady shear flows over holes and slits, vortex shedding from intrusions	Tonal
Inflow turbulence noise	Interaction of blade with atmospheric turbulence	Broadband
Steady thickness noise, steady loading noise	Rotation of blades or rotation of lifting surface	Low frequency related to blade-passing frequency (outside of audible range)
Unsteady loading noise	Passage of blades through varying velocities, due to pitch change or blade altitude change as it rotates; for downwind turbines, passage through tower shadow	Whooshing or beating, amplitude modulation of audible broadband noise; for downwind turbines, impulsive noise at blade-passing frequency

Abbreviations: f = frequency

Sources: Ellenbogen et al. (2012); Wagner, Bareiss and Guidati (1996)

Measurement of sound from wind turbines

Deriving a single SPL from wind turbines in the presence of background noise is difficult. Numerous factors (e.g. meteorological conditions, wind turbine spacing, wake and turbulence effects, vortex effects, turbine synchronicity, tower height, blade length and power settings) contribute to the sound levels heard or perceived at residences. Perception of wind farm sound would also depend on any building resonance effects for residents living inside a dwelling (Thorne 2011).

Modelled or estimated sound pressure level

Prediction of an SPL (a modelled SPL), at a specific distance from a wind turbine source with a known power level, requires knowledge of the propagation of sound waves. In general, the SPL decreases as sound propagates without obstruction from a point source. The SPL is reduced by 6 dB per doubling of distance. If the source is on a perfectly flat and reflecting surface, then hemispherical spreading is assumed. An accurate sound propagation model to estimate SPL usually considers the following factors (Beranek & Ver 1992; Ellenbogen et al. 2012; Rogers, Manwell & Wright 2006):

- source characteristics including directivity and height
- distance from the source
- air absorption, which depends on frequency
- ground effects (reflection/absorption of sound on the ground, which is influenced by turbine height, the terrain cover and ground properties between the source and the receiver)
- the presence of obstructions and uneven terrain
- weather effects (i.e. wind direction and speed/change, temperature variation with height)
- topography (landscape—land forms can focus sound).

Overall, using a ‘conservative’ assumption of a model of hemispherical propagation over a reflective surface, the following formula can be used to predict the SPL (L_p):

$$L_p = L_w - 10\log_{10}(2\pi r^2) - \alpha r$$

where r is the distance from the sound source radiating at power level L_w (dB), and α is the frequency-dependent sound absorption coefficient ($\alpha = 0.005$ dB/m) (Rogers, Manwell and Wright 2006).

The total sound produced by multiple wind turbines can be estimated by summing the sound levels caused by each turbine at a specific location³¹ (Rogers, Manwell and Wright 2006). For multiple wind turbines (N) in close proximity, the total sound power can be estimated by:

$$L_{total} = 10\log_{10}\sum 10^{L_i/10}$$

The sum $\sum$ is from turbine $i = 1$ to N^{th} turbine, and L_i is the sound power of the i^{th} turbine.

³¹ Note that decibels cannot be added numerically as linear measures.

The calculations become more ‘complicated’ when distances vary between turbines in a wind farm. Ellenbogen et al. (2012) provide a comprehensive discussion on these issues in their Appendix E.

Turbine sound in the international setting

The Danish Environmental Agency provided a summary of wind turbine measurements by turbine type, distance and conditions (wind, number of turbines etc.) from a number of published reports (Jakobsen 2005). These data are reproduced in Table 9. However, Jakobsen et al. (2005) noted that the measurement and operating conditions of the wind turbines were not described in detail in the individual reports, and that it was not possible to correct for background noise.

Table 9 Wind turbine measurements (conducted outdoors) by power, distance and conditions

Wind turbine type	Power rating, kW	Distance, m	Infrasound level, dB(G)	Conditions ^a
Monopteros 50	640	200	84	11 m/s
Encercon E-40	500	200	56–64	8 m/s
Vestas V66	1650	100	70	723 kW
Unknown	2000	200	59	6 m/s
		200	65	12 m/s
Bonus	450	80	65	9 m/s (4 turbines)
		100	71	8 m/s (1 turbine)
		200	63	10 m/s (1 turbine)
		100–200	70	9 m/s (4 turbines)
MOD-1	2000	105	107	No details provided
		1000	73–75	
WTS-4	4200	150	92	
		250	83–85	
MOD-5B	3200	68	71	
USWP-50	50	500	67–79	(14 turbines)
WTS-3	3000	750	68	No details provided
		2100	60	

(G) = to allow easier comparison between the different findings on infrasound emission, the G-weighted infrasound level was estimated by the authors. However, there were inadequate data to control for potentially different background noise levels, i.e. the impact of background noise on the measured noise level is not known.

Abbreviations: m/s = metres per second as a measurement of wind speed

^a For some conditions, the number of turbines is not provided.

Source: Jakobsen (2005)

Van den Berg et al. (2008) summarised SPLs from approximately 90 wind turbines in The Netherlands according to wind turbine type, power, hub height, rotor diameter and wind speed. When the data were plotted, it was apparent that, despite differences in power, hub height, rotor diameter and wind speed, the sound emission signatures were very similar across all types of wind turbine models. This was particularly the case in the mid-frequency range, 500–1000 Hz.

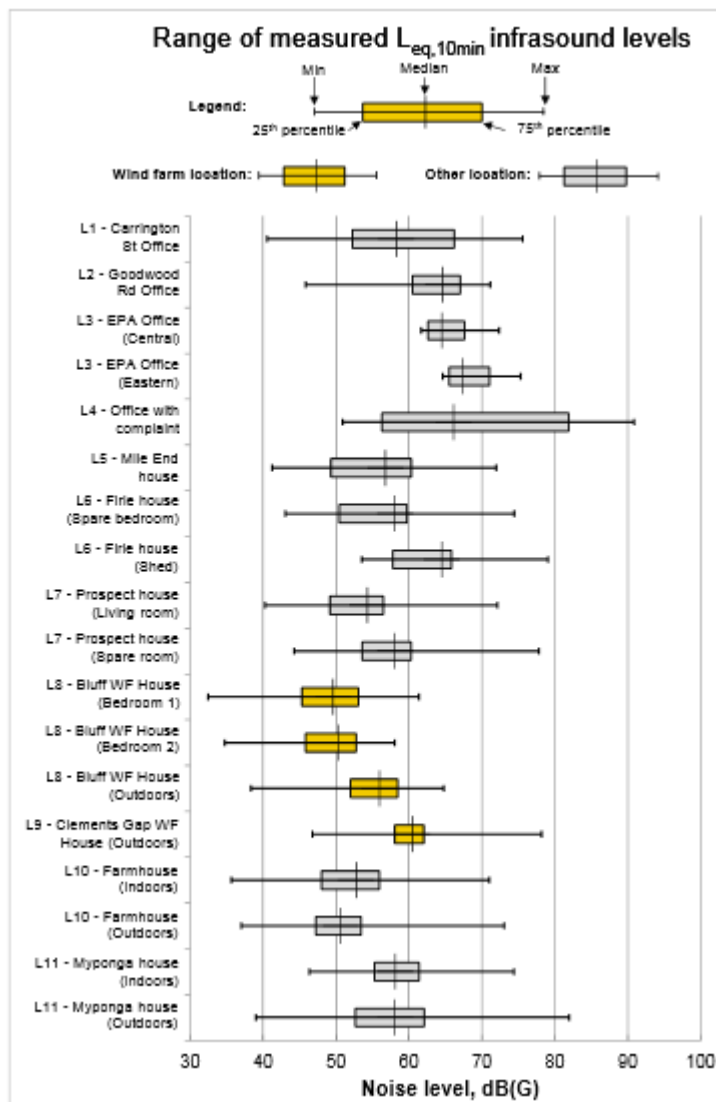
The Environmental Agency of North Rhein-Westphalia (LNW 2002) provided some data on SPLs by distance from a single wind turbine with a sound power level of 103 dB(A). Details as reproduced by Ellenbogen et al. (2012) are as follows:

- At a distance of 280 m from the turbine, the SPL corresponds to 45 dB(A).
- At a distance of 410 m from the turbine, the SPL corresponds to 40 dB(A).
- At a distance of 620 m from the turbine, the SPL corresponds to 35 dB(A).

Turbine sound in the national setting

A recent study by the Environment Protection Authority in South Australia (Evans, Cooper & Lenchine 2013) examined the level of infrasound within typical environments in South Australia. The key objective of the study was to compare two wind farm environments with urban (seven locations) and rural (four locations) environments away from wind farms. Both indoor and outdoor measurements were undertaken over a period of approximately 1 week at specified locations. Levels of background noise were also measured at residences approximately 1.5 km from the wind farms during organised shutdowns of the turbines.

Figure 4 summarises the range of measured $L_{eq, 10 \text{ minutes}}$ (equivalent noise level over a 10-minute measurement period) infrasound levels at each of the measurement locations in the study.



Source: Figure 1, p. iv of Evans, Cooper and Lenchine (2013)

Figure 4 Range of measured $L_{eq, 10 \text{ minutes}}$ infrasound levels at each measurement location

The study concluded that the level of infrasound at locations near wind turbines was no greater than that experienced in other urban and rural environments. The study also found that the contribution of wind turbines to the measured infrasound levels was insignificant in comparison with the background level of infrasound in the environment. The report noted the following:

- For the rural environments:
 - Outdoor infrasound levels were similar to, or marginally above, indoor infrasound levels.
 - Infrasound levels at houses near wind farms were not higher than those at houses located at significant distances from wind farms (e.g., the outdoor infrasound levels at one location 1.5 km from an operational wind farm were 'significantly' lower than those at another location at a distance of 30 km). Results at one of the locations near a wind farm were the lowest infrasound levels measured at any of the locations included in the study.

- Infrasound levels in the rural environment appear to be controlled by localised wind conditions where, during low wind periods, levels as low as 40 dB(G) were measured at locations both near and away from wind turbines. At higher wind speeds, infrasound levels of 50–70 dB(G) were common at both wind farm and non-wind-farm sites.
- For the urban environments:
 - Infrasound levels of between 60 and 70 dB(G) commonly occur in the urban environment (levels were typically 5–10 dB(G) higher during the day than at night).
 - Noise generated by people and associated activities within a space was one of the most significant contributors to measured infrasound levels, which were typically 10–15 dB(G) higher when a space was occupied. Infrasound levels up to approximately 70 dB(G) were measured in occupied spaces.
 - Traffic influenced the infrasound level in an urban environment, with measured levels during daytime periods typically 10 dB(G) higher than between midnight and 6 am, when traffic activity is likely to be at its lowest.
 - At two locations, including a site with a low-frequency noise complaint, building air conditioning systems were identified as significant sources of infrasound (some of the highest levels of infrasound measured during the study were exhibited at these sites).

Overall, measured G-weighted infrasound levels at rural locations both near and away from wind farms were no higher than infrasound levels measured at the urban locations. Both outdoor and indoor infrasound levels were well below the perception threshold, and the most apparent difference between the urban and rural locations was that human/traffic activity appeared to be the primary source of infrasound in urban locations, while localised wind conditions were the primary source of infrasound in rural locations.

Wind farm noise limits in Australia

New South Wales, South Australia, Tasmania, Victoria and Western Australia all have general noise limits applicable to wind turbines (Table 10).

Table 10 Australian state and territory noise level limits

State/territory	Guidance document for assessment	Minimum noise level limit ^a	Penalty for noise characteristics	Comments
ACT	-	-	-	Wind farm guidance has not been prepared.
New South Wales	South Australia Environment Protection Authority (EPA) <i>Environmental noise guidelines: Wind farms, 2003</i>	$LA_{eq, 10 \text{ minutes}}$ 35 dB	5 dB	Penalty applies for tonality only. No other characteristics are assessed directly.
Northern Territory	-	-	-	There is no specific wind farm assessment document. Developments would likely be assessed on a case-by-case basis.
Queensland	-	-	-	There is no specific guidance regarding wind farms. Developments would likely be assessed on a case-by-case basis. NZS6808: 1998 and South Australia EPA Guidelines 2003 have been referred to previously.
South Australia	South Australia Environment Protection Authority <i>Wind farms environmental guidelines 2009</i>	LA_{90} 35–40 dB	5 dB	Penalty applies for tonality only. No other characteristics are assessed directly.
Tasmania	Department of Primary Industries,	-	5 dB	General guidance on the assessment of wind farm noise emission is provided in the TNMP,

State/territory	Guidance document for assessment	Minimum noise level limit ^a	Penalty for noise characteristics	Comments
	Water and Environment (Tasmania), <i>Noise Measurement Procedures Manual</i> , 2004 (TNMP)			but limits are not explicitly stated and would likely be assessed on a case-by-case basis. A 5 dB penalty applies for one characteristic. The maximum penalty is 10 dB. Amplitude modulations, impulsiveness, low-frequency noise and tonality are considered.
Victoria	New Zealand Standard NZ 6808: 1998 <i>Acoustics – the assessment and measurement of sound from wind turbine generators</i>	LA_{95} 40 dB	5 dB	-
Western Australia	<i>Environmental Protection (Noise) Regulations 1997</i> . Guidance for the Assessment of Environmental Factors No. 8 – Environmental Noise, s3.2.2 (draft, May 2007)	-	The WA noise regulations specify adjustments of 5 dB for tonality and modulation and 10 dB for impulsiveness to be added to the LA_{slow} level, to a maximum of 15 dB.	Additionally, the Western Australian government document, <i>Guidelines for wind farm development</i> , suggests that turbines are set back at least 1 km.

Note: Where minimum noise level limits have been established in a state or territory, it has generally been in conjunction with a variation of the limit in periods of high background noise.

Source: EPHC (2010)

Systematic literature review

SQ1. IS THERE ANY RELIABLE EVIDENCE OF AN ASSOCIATION BETWEEN DISTANCE FROM WIND TURBINES AND ADVERSE HEALTH EFFECTS?

SQ2. IS THERE ANY RELIABLE EVIDENCE OF AN ASSOCIATION BETWEEN AUDIBLE NOISE (GREATER THAN 20 HZ) FROM WIND TURBINES AND ADVERSE HEALTH EFFECTS?

Seven cross-sectional studies (discussed in 11 articles) (level IV aetiology evidence) reported on the health effects of wind turbine noise exposure. Five of the studies could be clearly defined as reporting noise exposure within the audible range on the basis of reporting estimates of exposure in dB(A); the remaining two studies have been included in the analysis even though they report only distance from a wind turbine or wind farm, because distance from wind turbines can be considered to be a surrogate for sound pressure level (SPL).

A profile of each study is given in Table 7 (page 46), along with a consideration as to how bias, confounding and chance may have affected the validity of the results produced. Detailed study profiles are given in APPENDIX B.

Members of one research group were involved in the conduct of three of the included studies (SWE-00, SWE-05, NL-07) that are discussed in six articles (Bakker et al. 2012; Pedersen 2011; Pedersen & Larsman 2008; Pedersen et al. 2009; Pedersen & Persson Waye 2004, 2007).

Results of all the studies are presented according to the different effects measured, including self-reported health effects (i.e. physical and mental health); and other health-related effects such as quality of life, sleep quality and sleep disturbance. Data on health-related effects were extracted because they can be related to stress, which is a possible mediator or moderator of health outcomes. Data on the association between annoyance and health outcomes within populations exposed to different levels of noise exposure (sound levels or distance from wind turbines) were also extracted.

Association between wind turbine noise and physical health effects

Six studies reported on the association between estimated sound pressure from wind turbines and self-reported physical health effects (studies SWE-00, SWE-05 and NL-07; see Table 11, as reported in the re-analysis of these data by Pedersen (2011)) or distance from wind turbines and self-reported health outcomes (Krogh et al. 2011; Nissenbaum, Aramini & Hanning 2012; Shepherd et al. 2011; see Table 12). A publication on study NL-07 examined possible independent predictors for each of the health outcomes (van den Berg et al. 2008) (see Table 13). Each of the six studies adjusted for different plausible confounders, some to a greater extent than others, but all still had the potential for confounded results (see Table 7, page 46).

Pedersen (2011) contrasted health outcome data from three studies that the author had been involved in, in a re-analysis. The results from the two Scandinavian studies (SWE-00 and SWE-05) and the Dutch study (NL-07), presented in the form of odds ratios (OR) and their 95% confidence intervals (95% CIs), are shown in Table 11. An OR above 1.00 suggests that there is a positive association between the dependent variable (in this case a health condition) and the independent

variable (e.g. estimated SPL); that is, the frequency of the health condition increases as the SPL increases. An OR below 1.00 suggests the opposite. The 95% CI indicates the extent of uncertainty in the OR. Thus, for example, if an OR is above 1.00 but its lower 95% CI bound is below 1.00, there might be no association between the health condition and SPL, or the frequency of the health condition might even be reduced with increasing sound pressure.

Only one of the self-reported health conditions investigated in studies SWE-00, SWE-05 and NL-07, tinnitus, had an OR that was above 1.00 and a lower confidence bound that was greater than 1.00. This association between self-reported tinnitus and SPL was observed only in SWE-00 (Pedersen & Persson Waye 2004) and was not replicated in either SWE-05 or NL-07. Similarly, the weak evidence (trend) of a positive association between SPL and prevalence of self-reported diabetes in SWE-05 (Pedersen & Persson Waye 2007) was not replicated in SWE-00 or NL-07. In these single studies the analyses had all been adjusted for age and gender; however, NL-07 also adjusted for economic benefit (see page 77). Overall, physical health (as measured using slightly different tools) did not appear to vary with estimated level of exposure to noise or distance from wind turbines.

When there are multiple comparisons conducted using statistical analysis, there is always the possibility that a statistically significant association may occur by chance. If a p value of 0.05 is used, when 20 statistical tests are performed in the one study it is likely that one statistically significant result will be spurious. One method of dealing with this is to use the Bonferroni correction, which adjusts the p value for the number of comparisons made. The original (2004) publication of SWE-00 used a Bonferroni correction in the statistical analysis, although it did not present any health outcome data. It is unclear whether the re-analysis of the SWE-00 data in Pedersen (2011), which analysed self-reported health effects across SWE-00, SWE-05 and NL-07, included a Bonferroni correction, as it is not mentioned. However, the concept of multiple statistical tests causing spurious associations is mentioned in Pedersen (2011) and, appropriately, the author only considered associations to be meaningful when they were consistently present across all three studies.

Table 11 Association between estimated A-weighted sound pressure levels from wind turbines and specific physical health effects (OR, 95%CI)

Study	Self-reported health outcome	SWE-00 ^a N ^c =319–333	SWE-05 ^a N ^c =720–744	NL-07 ^b N ^c =639–678
Comparison of studies NL-07, SWE-00 and SWE-05 Pedersen (2011)	Chronic disease	0.97 (0.89, 1.05)	1.01 (0.96, 1.07)	0.98 (0.95, 1.01)
	Diabetes	0.96 (0.79, 1.16)	1.13 (1.00, 1.27)	1.00 (0.92, 1.03)
	High blood pressure	1.03 (0.90, 1.17)	1.05 (0.97, 1.13)	1.01 (0.96, 1.06)
	Cardiovascular disease	0.87 (0.68, 1.10)	1.00 (0.88, 1.13)	0.98 (0.91, 1.05)
	Tinnitus	1.25 (1.03, 1.50)	0.97 (0.88, 1.07)	0.94 (0.85, 1.04)
	Impaired hearing	1.09 (0.93, 1.27)	1.05 (0.95, 1.15)	1.01 (0.94, 1.10)
	Headache	0.95 (0.88, 1.02)	1.04 (0.99, 1.10)	1.01 (0.98, 1.04)

Bolded values indicate statistically significant differences.

Abbreviations: OR = odds ratio; CI = confidence interval

^a Adjusted for age and gender.

^b Adjusted for age, gender and economic benefits.

^c Range of number of respondents in the analyses. Differences in number of respondents are due to respondents not answering some individual questions in the questionnaire.

Similar to the results of the three studies above, Shepherd et al. (2011), Krogh et al. (2011) and Nissenbaum, Aramini and Hanning (2012) assessed whether respondents living closer to wind turbines had any more physical health complaints than those who were living further away, with the understanding that distance from a wind turbine is a proxy for the level of noise exposure from the turbine (Table 12).

Krogh et al. (2011) noted that a greater percentage of respondents living close to wind turbines reported altered health, headaches, migraines, hearing problems and tinnitus than those living further away from wind turbines, but the differences were not statistically significant. The rates of health complaints were high across both distance groups, which is probably a result of biased selection. Study locations were chosen specifically because adverse health effects had been anecdotally reported, and those with health complaints would probably be more likely to respond to the survey, given the lack of masking of study intent.

Although all the studies were of poor quality, one strength of both Shepherd et al. (2011) and Nissenbaum, Aramini and Hanning (2012) was the use of validated questionnaires to measure self-reported physical health. Shepherd et al. (2011) assessed general health with a single item in an abbreviated version of the World Health Organization Quality of Life questionnaire (WHOQOL-

BREF), while Nissenbaum, Aramini and Hanning (2012) measured physical health status using the Physical Component Summary Scale of version 2 of the Short Form-36 item questionnaire. Krogh et al. (2011) assessed general health with an author-developed non-standardised survey. Despite these differences, none of the studies reported any statistically significant associations between distance from wind turbines and self-reported physical health status over the different distances measured (Table 12).

Table 12 Association between distance from wind turbines (m) and physical health outcomes

Study	Self-reported health outcome	Proportion affected at distance (m) from nearest industrial wind turbine		P value
		<2000 n=39	>8000 n=158	
Shepherd et al. (2011) New Zealand N=198	WHOQOL-BREF self-rated general health	Not stated	Not stated	$t(195) = 0.37$, $p=0.71$
Krogh et al. (2011) ^a Canada N=109		350–673 (mean = 506) n=not stated	700–2400 (mean = 908) n=not stated	
	Altered health	94%	85%	0.19
	Headaches	70%	53%	0.10
	Migraines	18%	9%	0.24
	Hearing problems	38%	32%	0.67
	Tinnitus	60%	51%	0.42
	Heart palpitations	32%	36%	0.68
	Approached doctor	38%	38%	1.00
Nissenbaum, Aramini and Hanning (2012) USA N=79		350–673 (mean = 506) n=not stated	700–2400 (mean = 908) n=not stated	
	Mean SF-36v2 ^b Physical Component Score	Not stated	Not stated	0.99

^a Statistical analyses performed by Fisher's exact test. Age and gender were included in the model if significant at $p<0.05$.

^b SF-36v2 = version 2 of the Short Form 36 item questionnaire.

SQ1, SQ2/BQ6. IS THERE EVIDENCE THAT THERE ARE CONFOUNDING FACTORS OR EFFECT MODIFIERS THAT MIGHT EXPLAIN THE ASSOCIATION OF WIND TURBINES WITH ADVERSE HEALTH EFFECTS?

When van den Berg et al. (2008) assessed the results of NL-07 in detail (Table 13), age was found to be associated with self-reported chronic disease, diabetes, high blood pressure and cardiovascular disease (i.e. the older the respondent, the more likely they were to have reported symptoms), while gender was associated with migraine (females were more likely to report migraines than males). Thus, if either of these confounders were differentially distributed among residents living either near or far from a wind farm or in different SPL exposure groups, it might explain the associations between wind farms and the odd health effect that is observed in some studies. In Pedersen's re-analysis (Pedersen 2011), NL-07 study results were adjusted for age, gender and economic benefit and found no association between estimated SPLs and health complaints (Table 11). SWE-00 (and SWE-05) only adjusted for age and gender and found an association with tinnitus. Table 7 (page 46) provides additional information on plausible confounders that were not addressed in all 3 studies.

Shepherd et al. (2011) did not report adjusting for potentially confounding factors such as age, gender, economic benefits or predisposing health complaints. Krogh et al. (2011) mentioned that they would have adjusted for age and gender, had the univariate results been statistically significant.

Table 13 Estimated A-weighted sound pressure levels, age, gender and economic benefit, as possible independent predictors of health outcomes in multivariate models analysed in the Dutch study (NL-07)

Study	Self-reported health outcome	Independent variables in multivariate model	Association of independent variable with health outcome OR (95%CI)
NL-07 Van den Berg et al. (2008) The Netherlands	Chronic disease	Sound levels	0.98 (0.95, 1.01)
		Economic benefits (no; yes)	0.70 (0.35, 1.43)
		Age (years)	1.03 (1.01, 1.04)
		Gender (male; female)	1.18 (0.82, 1.70)
	Diabetes	Sound levels	1.00 (0.92, 1.09)
		Economic benefits (no; yes) ^a	NC
		Age (years)	1.07 (1.03, 1.11)
		Gender (male; female)	0.69 (0.28, 1.70)
	High blood pressure	Sound levels	1.01 (0.96, 1.06)
		Economic benefits (no; yes)	0.15 (0.02, 1.20)
		Age (years)	1.06 (1.04, 1.08)

Study	Self-reported health outcome	Independent variables in multivariate model	Association of independent variable with health outcome OR (95%CI)
	Tinnitus	Gender (male; female)	1.27 (0.96, 1.06)
		Sound levels	0.94 (0.85, 1.04)
		Economic benefits (no; yes)	0.90 (0.10, 8.42)
		Age (years)	1.03 (0.99, 1.06)
		Gender (male; female)	1.26 (0.05, 3.36)
	Hearing impairment	Sound levels	1.01 (0.94, 1.10)
		Economic benefits (no; yes)	0.38 (0.04, 3.31)
		Age (years)	1.05 (1.03, 1.10)
		Gender (male; female)	0.60 (0.26, 1.37)
	Cardiovascular disease	Sound levels	0.98 (0.91, 1.05)
		Economic benefits (no; yes)	0.39 (0.05, 3.26)
		Age (years)	1.06 (1.03, 1.09)
		Gender (male; female)	0.61 (0.29, 1.27)
	Migraine	Sound levels	0.93 (0.83, 1.04)
		Economic benefits (no; yes) ^a	NC
		Age (years)	0.98 (0.94, 1.01)
		Gender (male; female)	13.2 (1.70, 101.86)

Bolded values indicate statistically significant differences.

Abbreviations: OR = odds ratio; CI = confidence interval; NC = not calculable

^a No respondents who benefited economically had reported this chronic disease or any symptoms.

Association between wind turbine noise and mental health effects

Five studies assessed the relationship between modelled A-weighted sound pressure and psychological distress (SWE-00, SWE-05 and NL-07), or distance from a wind turbine (as a proxy for noise exposure) and mental health (Krogh et al. 2011; Nissenbaum, Aramini & Hanning 2012). A higher estimated exposure to wind turbines (in this case, dwelling at a closer distance) was associated with poorer self-reported mental health in one of the five studies (Nissenbaum, Aramini & Hanning 2012).

It is unclear what tools were used to determine whether respondents were tense and stressed or irritable in the two Swedish studies (SWE-00 and SWE-05). The results of these two studies were consistent with NL-07 in not observing an association between SPL and being tense and stressed or irritable (Table 14).

Van den Berg et al. (2008) was explicit that study NL-07 measured psychological distress by the General Health Questionnaire (GHQ), with a scale ranging from 0 to 12. The variable was dichotomised into 'not psychologically distressed' and 'psychologically distressed' using a cut-off of 2 or above for the latter. However, stress scores were calculated from 13 items, with a 4-point scale from '(almost) never' to '(almost) daily', with response factors analysed so that the mean value was 0 and the standard deviation was 1. Six items were used to describe the symptoms of stress: feeling tense or stressed, feeling irritable, having mood changes, being depressed, suffering from undue tiredness and having concentration problems. Levels of A-weighted sound pressure were not associated with psychological distress or stress scores when other factors such as economic benefits, age and gender were taken into account (Table 15).

Table 14 Association between estimated A-weighted sound pressure levels and stress

Study	Self-reported outcome	SWE-00^a OR (95%CI) N^c=319–333	SWE-05^a OR (95%CI) N^c=720–744	NL-07^b OR (95%CI) N^c=639–678
Comparison of studies NL-07, SWE-00 and SWE-05 Pedersen (2011)	Tense and stressed	1.02 (0.94, 1.10)	1.00 (0.95, 1.05)	1.01 (0.98, 1.04)
	Irritable	1.03 (0.96, 1.11)	1.00 (0.96, 1.06)	1.01 (0.98, 1.04)

Abbreviations: OR = odds ratio; CI = confidence interval

^a Adjusted for age and gender.

^b Adjusted for age, gender, and economic benefits.

^c Range of number of respondents in the analyses. Differences in number of respondents are due to missing cases; that is, the respondents not answering single questions in the questionnaire.

Table 15 Relationship between estimated A-weighted sound pressure levels, other possible confounding factors and psychological distress or stress in study NL-07

Study	Self-reported health outcome	Independent variables in multivariate model	Association of independent variables with health outcome OR (95%CI)
NL-07 Van den Berg et al. (2008) The Netherlands	Psychological distress on GHQ (<2; >2) (n=656)	Sound levels	1.02 (0.99, 1.06)
		Economic benefits (no; yes)	0.74 (0.41, 1.34)
		Age (years)	0.99 (0.99, 1.00)
		Gender (male; female)	1.12 (0.78, 1.58)
	Stress scores (<0; ≥0.01) (n=656)	Sound levels	1.01 (0.98, 1.04)
		Economic benefits (no; yes)	0.61 (0.35, 1.07)
		Age (years)	0.98 (0.97, 0.99)
		Gender (male; female)	1.32 (0.83, 1.64)

Bolded values indicate statistically significant differences.

Abbreviations: OR = odds ratio; CI = confidence interval

Two studies assessed the relationship between distance from wind turbines and mental health (Table 16). Nissenbaum and colleagues (2012) used the Mental Component Summary Scale of the Short Form-36 item questionnaire (version 2), a validated instrument, but did not control for all plausible confounders (see Table 7, page 46). They found that the mental health scores of residents living either near wind farms or further away were both within the normal range (population norm, mean = 50, SD = 10), although the mean value indicated poorer mental health for residents living near wind farms ($p=0.002$). Participants were not masked to the intent of the study and so it likely that recall bias may also have influenced the findings. Nissenbaum and colleagues also found that participants living close to a wind turbine (375–1400 m) were much more likely to self-report a new diagnosis of depression or anxiety since the introduction of the wind turbines than the ‘far’ group (living over 3 km from a wind turbine). Similarly, participants in the ‘near’ group reported a greater amount of new psychotropic medication being taken than those in the ‘far’ group, although the difference was not statistically significant.

Krogh et al. (2011), using a purpose-designed questionnaire, did not detect any significant differences in the rates of self-reported stress, anxiety or depression. The difference between these results and those reported by Nissenbaum, Aramini and Hanning (2012) could be due to various factors including sample selection, the impact of plausible confounders (see Table 7, page 46), measurement tool/question used, and difference in residential distance from turbines.

Table 16 Relationship between distance and self-reported mental health

Study	Self-reported health outcome	Proportion affected at distance (m) from nearest industrial wind turbine		P value
Krogh et al. (2011) Canada N=109		350–673 (mean = 506) n=not stated	700–2400 (mean = 908) n=not stated	
	Stress	66%	72%	0.52
	Anxiety	54%	49%	0.69
	Depression	46%	36%	0.41
	Distress (if at least one of stress, anxiety or depression were reported as 'yes')	68%	77%	0.37
Nissenbaum, Aramini and Hanning (2012) USA N=79		375–1400 (mean = 792) n=38	3000–6600 (mean = 5248) n=41	
	New diagnosis of depression or anxiety	9/38 (23.6%)	0/41 (0%)	Not stated
	New psychotropic medication	9/38 (23.6%)	3/41 (7.3%)	0.06
	Mean SF36v2 ^a Mental Component Score	42.0	52.9	p=0.002

^a SF-36v2 = version 2 of the Short Form 36 item questionnaire.

Association between wind turbine noise and quality of life

Three studies reported on the association between distance from wind turbines and quality of life (QoL) (Krogh et al. 2011; Nissenbaum, Aramini & Hanning 2012; Shepherd et al. 2011); the results of the studies are shown in Table 17.

Shepherd et al. (2011) compared QoL in respondents who lived less than 2 km or greater than 8 km from a wind turbine. This cross-sectional study attempted to mask the intent of the study by asking about annoyance from traffic noise, neighbours or 'other noise (please specify)'. Overall QoL was assessed using a single question in the abbreviated World Health Organization Quality of Life questionnaire (WHOQOL-BREF). This questionnaire was also used by the authors for measurements on several domains, including physical (7 items), psychological (6 items), environmental (8 items) and social (3 items) QoL. Shepherd et al. (2011) found that those living nearer to wind turbines had significantly lower scores than those who lived further away, in the domains of physical ($F(1,194) = 5.816$, $p=0.017$), environmental ($F(1,194)=5.694$, $p=0.018$) and

mean self-rated overall QoL ($t(195)=2.364$, $p=0.019$), as well as on an additional amenity-rating question added by the authors ($F(1,194)=18.88$, $p<0.001$). The absolute difference in QoL between the groups for each domain was less than 10%. Perceived sleep quality was one facet of the physical domain that showed a difference between the groups ($t(195)=3.089$, $p=0.0006$), as did self-reported energy levels ($t(195)=2.217$, $p=0.028$), but the absolute differences between groups in these aspects of QoL were not reported. Psychological and social domains did not show any significant differences between the groups. Results were not adjusted for all plausible confounders (Table 7, page 46).

Krogh et al. (2011) only included people in their study who lived less than 2400 m from a wind turbine, and nearly all respondents (96–98%) answered ‘yes’ to the non-masked survey question ‘Do you feel that your quality of life has in any way altered since living near wind turbines?’

Nissenbaum, Aramini and Hanning (2012) asked respondents whether they wished to move away. The majority of those living less than 1.4 km from a wind turbine responded in the affirmative (74%), whereas none of the group who lived over 3 km from a wind turbine wished to move.

Table 17 Association between distance from a wind turbine and quality of life

Study	Self-reported outcome measure	Mean scores or proportion affected at distance (m) from nearest industrial wind turbine		Statistic	p value
Shepherd et al. (2011) New Zealand N=198		<2000 n=39	>8000 n=158		
	Psychological domain ^a	22.36±2.67	23.29±2.91	$F(1,194)=3.33$	$p=0.069$
	Physical domain ^a	27.38±3.14	29.14±3.89	$F(1,194)=5.82$	$p=0.017$
	Self-reported energy levels	Not stated	Not stated	$t(195)=2.2$	$p=0.028$
	Perceived sleep quality ^a	Not stated	Not stated	$t(195)=3.09$	$p=0.0006$
	Social domain ^a	12.53±1.83	12.54±2.13	$F(1,194)=0.002$	$p=0.96$
	Environmental domain ^a	29.92±3.76	32.76±4.41	$F(1,194)=5.69$	$p=0.018$
	Amenity	7.46±1.42	8.91±2.64	$F(1,194)=18.88$	$p<0.001$
	WHOQOL-BREF overall quality of life	Not stated	Not stated	$t(195)=2.36$	$p=0.019$

Study	Self-reported outcome measure	Mean scores or proportion affected at distance (m) from nearest industrial wind turbine		Statistic p value
Krogh et al. (2011) Canada N=109		350–673 (mean = 506) n=not stated	700–2400 (mean = 908) n=not stated	
	Altered quality of life	96%	98%	p=1.00
Nissenbaum, Aramini and Hanning (2012) USA N=79		375–1400 (mean = 792) n=38	3000–6600 (mean = 5248) n=41	
	Wishing to move away	73.7%	0%	p<0.001

Bolded values indicate statistically significant differences.

^a Mean ± standard deviation. A high score indicates better QoL. The WHOQOL-BREF psychological domain has a maximum score of 30, the physical domain has a maximum score of 35, and the social domain has a maximum score of 15, while the environmental domain has a maximum score of 40. The raw domain scores do not appear to have been transformed to a 0–100 scale.

Other relevant outcomes

Association between wind turbine noise and sleep disturbance

All seven studies assessed the association between estimated wind turbine noise and sleep disturbance or sleep quality. Three studies assessed the association between sleep and estimated A-weighted SPL (SWE-00, SWE-05, NL-07), while the four remaining studies assessed the relationship between distance from a wind turbine and sleep quality. Only subjective sleep measures were used. There were no studies that measured sleep objectively.

One article (Pedersen 2011) summarised the two Scandinavian studies and the one Dutch study (SWE-00, SWE-05 and NL-07), and reported that there was an association between estimated A-weighted SPL and the frequency of sleep disturbance in one of the studies, as determined subjectively by the respondents ('(almost) never', 'at least once a year', 'at least once a month', 'at least once a week', and '(almost) daily'). A minimum of at least once a month was considered to be sleep disturbance. The results are shown in Table 18. The first Swedish study (SWE-00) reported that increases in estimated SPL increased the odds of having sleep interruption due to estimated wind turbine noise. Results were similar in the Dutch study, where a trend was observed. The second Swedish study (SWE-05), carried out in more densely populated areas, did not report a statistically significant association between estimated SPL and sleep disturbance. Pedersen hypothesised that a combination of lowered expectations of quietness and higher levels of background noise could have explained this lack of association (Pedersen 2011).

Pedersen and Persson Waye (2004) reported from study SWE-05 that 23% of respondents had stated that their sleep was disturbed by noise from road traffic, rail traffic, neighbours or wind turbines. At lower estimated exposure to noise from wind turbines, no respondents reported sleep disturbance, whereas 16% of the respondents exposed to sound over 35 dB(A) reported disturbed sleep. Of these, 18/20 reported sleeping with an open window in the summer. In the Dutch sample (study NL-07), described in van den Berg et al. 2008, 30% of respondents reported difficulties in falling asleep at least once a month, while 25% reported interrupted sleep at least once a month. Paradoxically, those exposed to the greatest estimated A-weighted SPLs from wind turbines had the least difficulty falling asleep, while those exposed to the least A-weighted SPLs had the most difficulty falling asleep. However, this trend largely disappeared when adjusted for possible confounding by age, gender and economic benefit (Table 19).

The association of estimated *SPL* on sleep interruption in the SWE-00, SWE-05 and NL-07 studies was not as strong as the association of wind turbine noise *annoyance* with sleep interruption (see Table 26).

Table 18 Association between estimated A-weighted sound pressure levels and sleep disturbance (OR, 95%CI)

Study	Self-reported outcome	SWE-00^a OR (95%CI) N^c=319–333	SWE-05^a OR (95%CI) N^c=720–744	NL-07 OR (95%CI) or % N^c=639–678
Comparison of studies NL-07, SWE-00 and SWE-05 Pedersen (2011)	Sleep interruption	1.12 (1.03, 1.22)	0.97 (0.90, 1.05)	1.03 ^b (1.00, 1.07)
	Undue tiredness	0.95 (0.88, 1.02)	0.98 (0.93, 1.03)	1.02 ^b (0.99, 1.05)
NL-07 Van den Berg et al. (2008) The Netherlands	Difficulties in falling asleep	-	-	N=710 <30 dB(A): 36% 30–35 dB(A): 31% 35–40 dB(A): 28% 40–45 dB(A): 32% >45 dB(A): 16%
	Sleep interruption	-	-	N=718 <30 dB(A): 21% 30–35 dB(A): 26% 35–40 dB(A): 26% 40–45 dB(A): 26% >45 dB(A): 28%

Bolded values indicate statistically significant differences.

Abbreviations: OR = odds ratio; CI = confidence interval

^a Adjusted for age and gender.

^b Adjusted for age, gender, and economic benefits.

^c Range of number of respondents in the analyses. Differences in number of respondents are due to missing cases, that is, the respondents not answering single questions in the questionnaire.

BQ6. Is there evidence that there are confounding factors or effect modifiers that might explain the association of wind turbines with sleep disturbance?

Van den Berg et al. (2008) assessed the odds of respondents in NL-07 reporting difficulties falling asleep, or interrupted sleep, at least once a month with increasing SPL, while simultaneously controlling for other factors including economic benefits, age and gender (Table 19). They reported that difficulty falling asleep was positively correlated with age ($r_s=0.08$, $n=691$, $p<0.05$), with older respondents having more difficulty falling asleep. Conversely, having interrupted sleep was negatively correlated with age, with younger participants having more interrupted sleep ($r_s=-0.08$, $n=699$, $p<0.05$). Females more often had problems falling asleep than males, and those who did not economically benefit from wind turbines or were older tended to have more trouble falling asleep than others. Respondents who benefited economically were less likely to report having had interrupted sleep. Sound level was the only factor that was not statistically significant at predicting the likelihood of falling asleep. An increase in sound level was associated with a trend towards a small increase in risk of having interrupted sleep. Thus, the impact of confounders might explain the difference in results between NL-07 and SWE-00; the former study adjusted for economic benefits while the latter did not.

Table 19 Relationship between estimated A-weighted sound pressure levels, other possible confounding factors and sleep quality in study NL-07

Study	Self-reported outcome	Independent variables	Results OR (95%CI)
NL-07 (Van den Berg et al. 2008) The Netherlands	Falling asleep	Sound levels	0.99 (0.97, 1.03)
		Economic benefits (no; yes)	0.52 (0.27, 0.97)
		Age (years)	1.02 (1.01, 1.03)
		Gender (male; female)	1.47 (1.05, 1.06)^a
	Interrupted sleep	Sound levels	1.03 (1.00, 1.07)
		Economic benefits (no; yes)	0.45 (0.24, 0.84)
		Age (years)	1.00 (0.99, 1.01)
		Gender (male; female)	1.07 (0.75, 1.51)

Bolded values indicate statistically significant differences.

Abbreviations: OR = odds ratio; CI = confidence interval

^a Confidence interval incorrectly reported in article.

Association between wind turbine noise and sleep quality

All four studies that compared sleep quality in respondents living close to wind turbines, compared with further away, found at least one sleep-related outcome that was statistically significantly different between groups (3 studies) or trending that way (1 study). Results were not adjusted for all plausible confounders (Table 7, page 46). Some outcome measures were not statistically significant but still reported trends towards worse sleep in respondents who lived closer to wind turbines. The results are shown in Table 20.

Table 20 Association between sleep quality and distance from nearest wind turbine

Study	Self-reported outcome	Distance (m) from nearest industrial wind turbine		Difference
Shepherd et al. (2011) New Zealand N=197		<2000 n=39	>8000 n=158	(statistical tests and p values)
	Perceived sleep quality	% not stated	% not stated	$t(195)=3.089$, p=0.006
Krogh et al. (2011) Canada N=109		350–673 (mean = 506) n=not stated	700–2400 (mean = 908) n=not stated	p value
	Disturbed sleep	78%	60%	0.078
	Excessive tiredness	86%	66%	0.031
Morris (2012) Australia N=93		0–5000 n=41	5000–10,000 n=52	OR (95%CI)
	Disturbed sleep ^a	16/41 (39.0%)	11/52 (21.1%)	2.39 (0.96, 5.95)
Nissenbaum, Aramini and Hanning (2012) USA N=79		375–1400 (mean = 792) n=38	3000–6600 (mean = 5248) n=41	p value
	PSQI mean score	7.8	6.0	0.046
	PSQI score >5 ^b	65.8%	43.9%	0.07
	ESS mean score	7.8	5.7	0.03
	ESS score >10 ^c	23.7%	9.8%	0.13
	Mean worsening sleep post WTs ^d	3.1	1.3	<0.0001
	Improved sleep when away from WTs	14/28 (50%)	2/34 (5.8%)	<0.0001
	Average new sleep medications post WTs	13.2	7.3	0.47

Study	Self-reported outcome	Distance (m) from nearest industrial wind turbine		Difference
	New diagnoses of insomnia (n)	2	0	

Bolded values indicate statistically significant differences.

Abbreviations: OR = odds ratio; CI = confidence interval; PSQI = Pittsburgh Sleep Quality Index; ESS = Epworth Sleepiness Scale; WTs = wind turbines

^a Categorised on basis of reports such as cannot get to sleep; awoken; cannot return to sleep; wake in panic, sweat; wake due to ear pain, ear pressure, headache, nausea; had to move away; high blood pressure.

^b PSQI >5 is considered a 'poor sleeper'.

^c About 10–20% of general population has an ESS score >10.

^d New sleep problems +worsening sleep problems/2; strongly agree (5) – strongly disagree (1).

Shepherd et al. (2011) reported that perceived sleep quality (one of the variables assessed in the WHOQOL-BREF questionnaire) was worse in respondents who lived within 2 km of a wind turbine, compared with respondents who lived at least 8 km from a wind turbine ($t(195)=3.09$, $p=0.006$). Although this result is statistically significant, it is unclear what it meant in absolute terms for the respondents, as actual scores were not provided. Krogh et al. (2011) and Morris (2012) both used investigator-developed questionnaires that had not been validated to ascertain levels of disturbed sleep, and reported higher rates of disturbed sleep in respondents who lived closer to wind turbines than further away. The difference in disturbed sleep was not statistically significant in Krogh et al. (2011) ($p=0.078$) but the difference in level of 'excessive tiredness' was. The Australian study by Morris provided sufficient detail to permit the reviewers to determine a non-significant trend suggesting that those who lived within 5 km of a wind turbine had higher odds of reporting disturbed sleep than those who lived between 5 and 10 km away (OR 2.39 95% CI 0.96, 5.95).

Nissenbaum, Aramini and Hanning (2012) reported statistically significantly worse sleep in those who lived closer to wind turbines (less than 1.4 km) than those who lived further away (3.0–6.6 km) for the majority of sleep outcomes. For sleep quality, as measured on the Pittsburgh Sleep Quality Index (PSQI)³², mean scores were statistically higher in the group of respondents who lived closer to wind turbines. This corresponded to significantly worse sleep quality, sleep latency, sleep duration and habitual sleep efficiency; sleep disturbance; greater use of sleep medication; and more daytime dysfunction (Buysse et al. 1989). A score of over 5 on the PSQI is classified as a 'poor sleeper'. There were a higher percentage of respondents who met this classification in the 'near' group than the 'far' group, although the difference was not statistically significant. Both groups would be considered to have poor sleep quality.

In Nissenbaum, Aramini and Hanning's (2012) study, daytime sleepiness was measured by the Epworth Sleepiness Scale (ESS). The mean ESS in those closer to turbines was 7.8, compared with 5.7 for those further away ($p=0.03$). When the results were dichotomised to assess the percentage of those with a score of greater than 10, differences between the groups were not statistically

³² The scale is 0–21, with 0 being best sleep quality and 21 being worst sleep quality, and a score of 5 and above is indicative of poor sleep quality.

significant, although the absolute difference between the groups was greater than 10% (Table 20). This result should be interpreted in the context of the ESS's usefulness as a measure of sleepiness. The ESS is a scale that measures the likelihood of falling asleep in eight different situations. It is used to detect subjective problematic sleepiness in patients with sleep disorders and is not highly correlated with objective markers of sleepiness. Normal ranges vary according to the population studied, but generally scores of <9 indicate the absence of problematic sleepiness. In most patients with insomnia disorders, the ESS score is similar to, or lower than, controls.

As well as using the validated instruments of the PSQI and ESS, Nissenbaum, Aramini and Hanning (2012) asked respondents in their questionnaire whether they considered that their sleep had worsened since the introduction of a wind turbine near their house, and whether they had improved sleep when away from wind turbines. Those living further away from the turbine, on average, disagreed that their sleep had worsened, while those living closer, on average, neither agreed nor disagreed. Half of the participants living within 1.4 km of a wind turbine reported improved sleep when away from turbines, compared with less than 6% in the group who lived over 3 km from a wind turbine. The difference was statistically significant.

Association between wind turbine noise and annoyance

Four studies assessed levels of annoyance or disturbance due to wind turbine noise in groups of people exposed to different estimated SPLs and/or living at different distances from wind turbines. Although annoyance is not considered to be a health effect by itself (i.e. it is a response rather than an effect), it is associated with stress, which could be considered a mediator or a moderator of health outcomes or health-related effects. Conversely, those with impaired physical or mental health may be more vulnerable to annoyance (Laszlo et al. 2012). Pedersen, the author of the Scandinavian studies, describes being annoyed as having 'a lowered wellbeing', which 'should therefore be avoided' (Pedersen 2011).

The results of three studies (SWE-00, SWE-05 and NL-07) that reported on annoyance at wind turbine noise outdoors or indoors were combined in one publication (Pedersen 2011), and the results are shown in Table 21. Annoyance was treated as a binary outcome, with 'do not notice', 'notice but not annoyed' and 'slightly annoyed' responses combined and compared against responses of 'rather annoyed' and 'very annoyed'. All results shown were statistically significant, indicating that, at greater estimated A-weighted SPLs, respondents were more likely to report annoyance at wind turbine noise. However, in the Swedish study (SWE-05) estimated SPL was not an independent predictor of noise annoyance when analyses were controlled for visibility of wind turbines, background noise and/or area type (whether rural or urban, with complex or flat terrain) (Pedersen & Persson Waye 2007). Conversely, in the Dutch study (NL-07) reported by Pedersen et al. (2009), estimated SPL was observed to be associated with annoyance independently of economic benefit, visibility of wind turbines and area type (Table 24).

Table 21 Association between estimated A-weighted sound pressure levels (independent, continuous variables) and annoyance at wind turbine noise (OR, 95%CI)

Study	Outcome measure	SWE-00 ^a OR (95%CI) N ^c =319–333	SWE-05 ^a OR (95%CI) N ^c =720–744	NL-07 ^b OR (95%CI) N ^c =639–678
Comparison of studies NL-07, SWE-00 and SWE-05 Pedersen (2011) The Netherlands and Sweden	Annoyance outdoors	1.24 (1.13, 1.36)	1.14 (1.03, 1.27)	1.18 (1.12, 1.24)
	Annoyance indoors	1.38 (1.20, 1.57)	1.42 (1.17, 1.71)	1.20 (1.13, 1.27)

Bolded values indicate statistically significant differences.

Abbreviations: OR = odds ratio; CI = confidence interval

^a Adjusted for age and gender.

^b Adjusted for age, gender and economic benefits.

^c Range of number of respondents in the analyses. Differences in number of respondents are due to missing cases, that is, the respondents not answering single questions in the questionnaire.

Details of the rates of annoyance at wind turbine noise in SWE-00, SWE-05 and NL-07 are shown in Table 22. Pedersen and Persson Waye (2004) reported that, from study SWE-00, the relative odds of being annoyed by wind turbine noise was 1.9 per noise exposure category. The pseudo- R^2 was 0.13, suggesting that only 13% of the variance in annoyance could be explained by estimated A-weighted SPL (Table 22). In other words, estimated noise level was not a good predictor of annoyance.

In an unadjusted analysis Bakker et al. (2012) reported that, in a Dutch population (study NL-07), response to wind turbine sound outdoors was correlated with levels of wind turbine sound ($\rho^{33}=0.50$, $n=708$, $p<0.001$), with the proportions of respondents annoyed by the sound increasing as sound levels increased, up to 45 dB(A), after which the proportions decreased. Similarly, perception and annoyance increased with increasing estimated SPLs indoors ($\rho=0.36$, $n=699$, $p<0.001$) (Pedersen et al. 2009).

One Australian study analysed results by distance from a wind turbine reported on annoyance or disturbance by wind turbine noise (Table 23). This study asked “does the wind farm generate noise disturbance?” (Morris 2012). The study had a low response rate (40%) (risk of sample selection bias) and no masking of study intent (risk of recall bias), meaning that people more likely to report disturbance could have been more interested in participating in the survey. Those living closer to wind turbines had much greater odds of being disturbed during the day and night by wind turbine noise than those who lived further away. The disturbances listed were specified as vibration of

³³ Spearman’s rho.

building, noise (roaring, thumping, grinding, whining, drumming, constant rumbling, noise that can be heard over the television) and changes in behaviour required (have to keep windows shut, had to relocate lounge room to hear television). No adjustments were made for potential confounding factors such as age, gender or economic benefits.

Overall, the results of the four studies were consistent in showing that, at closer distances or greater sound levels, respondents were more likely to report being annoyed by wind turbine noise than if they lived at greater distances or experienced lower estimated SPLs. Three of the studies attempted to reduce recall bias by masking the studies' intent and asking about multiple sources of annoyance. Adjustment for confounding did not completely explain the effect.

Other possible determinants of annoyance from wind turbines

Economic benefit

Only one study (NL-07; reported in van den Berg et al. 2008 and Pedersen et al. 2009) assessed economic benefit as a possible determinant of reported noise annoyance from wind turbines. Respondents who received an economic benefit from the wind turbines were much less likely to report annoyance than those who did not receive an economic benefit. The OR for annoyance in those who received economic benefit relative to those who did not was 0.06 (95% CI 0.02, 0.23) after taking account of possible confounding by estimated SPL, visibility of wind turbines and area type (Pedersen et al. 2009, see Table 28). Thus, receiving an economic benefit from wind turbines *reduced* the odds of being annoyed by wind turbine noise.

Those living in a built-up area were less likely to benefit economically from wind turbines (2%) than those in rural areas (19%) (Pedersen et al. 2009).

Neither Pedersen et al. (2009) nor van den Berg et al. (2008), reporting on study NL-07, specified whether those who received economic benefits from wind turbines had a part in the decision regarding location of the wind turbines. Although it is possible that receiving an economic benefit reduced the likelihood of being annoyed, it is also possible that respondents who were favourable towards wind turbines prior to their construction (and less likely to be annoyed) were more likely to agree to have one placed close to their place of residence in exchange for an economic benefit. Given the cross-sectional design of study NL-07, the direction of the association cannot be determined.

Table 22 Association between estimated A-weighted sound pressure levels and annoyance (further details)

Study	Self-reported outcome	Results
SWE-00 Pedersen and Persson Waye (2004) Sweden N ^a =319–333	Annoyance (location not specified)	$\beta=0.63$, $p<0.001$, Exp(b) (OR) 1.9 (95%CI 1.5, 2.4) for increase in annoyance when moving from one sound category to the next ^b Pseudo-R ² =0.13
SWE-05 Pedersen and Persson Waye (2007) Sweden N=720–744	Annoyance (location not specified)	<37.5 dB(A): 3–4% 37.5–40 dB(A): 6% >40 dB(A): 15%
NL-07 Bakker et al. (2012) The Netherlands N=639–678	Annoyance (outdoors)	<30 dB(A): 4/178 (2%) 30–35 dB(A): 16/213 (8%) 35–40 dB(A): 28/159 (18%) 40–45 dB(A): 17/93 (18%) >45 dB(A): 8/65 (12%) Total: 73/708 (10%)
	Annoyance outdoors (no economic benefit)	<30 dB(A): 4/166 (2%) 30–35 dB(A): 16/199 (8%) 35–40 dB(A): 28/140 (20%) 40–45 dB(A): 15/60 (25%) >45 dB(A): 6/28 (21.4%) Total: 69/586 (12%)
	Annoyance indoors (no economic benefit)	<30 dB(A): 2/167 (1.2%) 30–35 dB(A): 8/191 (4.2%) 35–40 dB(A): 12/140 (8.6%) 40–45 dB(A): 15/60 (25%) >45 dB(A): 4/21 (19.0%) Total: 41/579 (7%)

Bolded values indicate statistically significant differences.

Abbreviations: OR = odds ratio; CI = confidence interval

^a Range of number of respondents in the analyses. Differences in number of respondents are due to missing cases; that is, the respondents not answering single questions in the questionnaire.

^b Upon being contacted, Professor Persson Waye clarified that this related to moving from any sound category to the next sound category, not just with respect to the reference category of <30 dB.

Table 23 Association between distance from nearest wind turbine and annoyance or disturbance

Study	Outcome measure	Proportion affected by distance (km) from nearest industrial wind turbine		OR (95%CI)
		0–5 n=41	5–10 n=52	
Morris (2012) Australia				
	Disturbed by noise during day	23/41 (56.1%)	13/52 (25%)	3.83 (1.59, 9.24)
	Disturbed by noise during night	22/41 (53.7%)	15/52 (28.8%)	2.86 (1.21, 6.74)

Bolded values indicate statistically significant differences.

Abbreviations: OR = odds ratio; CI = confidence interval

Terrain, urbanisation and visibility

Two studies looked at whether the type of terrain or urbanisation where the wind turbines and residences were located was associated with levels of annoyance (SWE-05 and NL-07). The results were slightly contradictory (Table 24). The Swedish study (SWE-05) reported that, even when estimated turbine noise exposure was controlled, respondents were more likely to be annoyed by ‘wind turbine noise’ if they lived in rural areas (compared with suburban), if they subjectively assessed the level of background noise as quiet or if they could see the wind turbine (Pedersen & Persson Waye 2007). The Dutch study (NL-07) found that there was a very slight association between annoyance and estimated SPLs when area type, visibility and economic benefit were controlled. However, consistent with SWE-00, living in a rural area near a main road was associated with reduced odds of being annoyed by wind turbine noise (living in a built-up area was the reference) when adjusted for estimated turbine SPLs, age, gender and economic benefit (van den Berg et al. 2008). This supports the concept of noise habituation; that is, people living in noisy areas are more habituated to noise than people living in quiet areas.

Both the Swedish (SWE-05) and Dutch studies (NL-07) reported that visibility of wind turbines increased the odds of noise annoyance to a large degree (although the actual magnitude of the effect was uncertain, as shown by the wide confidence intervals) (Table 24).

Table 24 Associations of terrain, urbanisation and visual factors with annoyance from wind turbine noise in multiple logistic regression models

Study	Variables included in multiple logistic regression models	ORs for annoyance from wind turbine noise (95% CI) ^a
SWE-05 Pedersen and Persson Waye (2007) N=720–744 Sweden	Sound pressure level (dB(A))	1.1 (1.0, 1.3)
	Terrain (complex; flat)	0.8 (0.4, 1.8)
	Sound pressure level (dB(A))	1.1 (1.0, 1.2)
	Suburban; rural	3.8 (1.8, 7.8)
	Sound pressure level (dB(A))	1.1 (1.0, 1.2)
	Suburban and flat (n=222) Reference category	1.0
	Suburban and complex (n=347)	2.1 (0.6, 7.3)
	Rural and flat (n=157)	5.2 (1.6, 16.7)
	Rural and complex ground (n=28)	10.1 (2.5, 41.6)
NL-07 Pedersen et al. (2009) The Netherlands	Sound pressure level (dB(A))	1.1 (0.9, 1.2)
	Subjective background noise (not quiet; quiet)	3.6 (1.2, 10.7)
	Sound pressure level (dB(A))	1.1 (0.9, 1.2)
	Vertical visual angle (degrees; +1 degree)	1.2 (1.0, 1.4)
	Sound pressure level (dB(A))	1.1 (1.0, 1.2)
NL-07 Van den Berg et al. (2008) The Netherlands	Visibility (no; yes)	10.9 (1.5, 81.9)
	Sound pressure level (dB(A))	1.1 (1.07, 1.21)
	Economic benefit (no; yes)	0.1 (0.02, 0.23)
	Visibility (no; yes)	13.7 (3.16, 57.4)
NL-07 Pedersen et al. (2009) The Netherlands	Area type (reference: rural)	
	Rural with main road	0.3 (0.17, 0.71)
	Built-up	1.9 (1.02, 3.59)
NL-07 Van den Berg et al. (2008) The Netherlands	Urbanisation ^b	
	Built-up area	1.0
	Rural area with a main road	0.20 (0.08, 0.45)
	Rural area without a main road	0.55 (0.28, 1.08)

Bolded values indicate statistically significant differences.

Abbreviations: OR = odds ratio; CI = confidence interval

^a Odds ratios and 95% CIs have been calculated from published beta coefficients and standard errors.

^b Adjusted for estimated turbine sound levels, age, gender and economic benefits.

Attitudes towards wind turbines

In all three European studies (SWE-00, SWE-05 and NL-07) data on attitudes towards wind turbines in general, attitudes towards the visual impact of wind turbines and subjective classifications of noise sensitivity of respondents were collected to ascertain how these factors are associated with reported annoyance from wind turbine sound (Table 25).

Pedersen and Persson Waye (2004) reported that, in the SWE-00 study, estimated SPL alone explained only 13% of the variance predicted by their model on wind turbine noise annoyance. When self-classified noise sensitivity was added to the logistic regression analysis, 18% of the variance was explained. However, when the attitude of the respondent towards the visual impact of wind turbines was added to estimated SPL in the model, 46% of the variance in noise annoyance was explained (Table 25)—suggesting that visual attitude is a strong predictor. These results are similar to the later Swedish study (SWE-05), which reported that a negative visual attitude increased the odds of being annoyed by the sound by over 14 times (Pedersen & Persson Waye 2007). Using data from the Dutch study (NL-07), Pedersen et al. (2009) undertook a multiple logistic regression analysis of the relationship between annoyance and estimated SPL (continuous scale), noise sensitivity, general attitude to wind turbines and visual attitude to wind turbines. The factor that had the greatest impact on annoyance was visual attitude, which had an OR of 2.8 per point increase on a 5-point scale. When visual attitude was assessed (with estimated SPL, age, sex and economic benefits controlled for, but not noise sensitivity or general attitude towards wind turbines), a negative attitude of the respondent towards the visual impact of wind turbines increased the odds of noise annoyance by over 4 times (OR=4.10, 95%CI 2.84, 5.91). It is unknown to what extent the general attitudes or visual attitudes towards wind farms precede the development of noise annoyance, or whether these attitudes changed in response to noise annoyance.

Table 25 Associations of noise sensitivity and attitudes to wind turbines with wind turbine noise annoyance

Study	Variables included in univariate or multiple logistic regression models	ORs for annoyance from wind turbines (95% CI) ^a
SWE-00 Pedersen and Persson Waye (2004) Sweden	Sound pressure level (dB(A))	1.8 (95%CI 1.5, 2.4) Pseudo- R^2 =0.13
	Sound pressure level (dB(A)) Noise sensitivity	1.9 (95%CI 1.5, 2.4) 1.9 (95%CI 1.5, 2.4) Pseudo- R^2 =0.18
	Sound pressure level (dB(A)) General attitude (not negative; negative)	1.9 (95%CI 1.5, 2.4) 1.7 (95%CI 1.3, 2.3) Pseudo- R^2 =0.20
	Sound pressure level (dB(A)) General attitude (not negative; negative) Noise sensitivity	1.9 (95%CI 1.5, 2.5) 1.8 (95%CI 1.3, 24.1) 1.8 (95%CI 1.2, 2.7) Pseudo- R^2 =0.24
	Sound pressure level (dB(A)) Visual attitude (not negative; negative)	1.7 (95%CI 1.3, 2.3) 1.7 (95%CI 1.3, 2.3) Pseudo- R^2 =0.46
	Sound pressure level (dB(A)) Visual attitude (not negative; negative) Noise sensitivity	1.8 (95%CI 1.3, 2.4) 4.9 (95%CI 3.1, 7.7) 1.25 (95%CI 0.8, 2.0) Pseudo- R^2 =0.47
	Sound pressure level (dB(A)) Visual attitude (not negative; negative) General attitude (not negative; negative) Noise sensitivity	1.8 (95%CI 1.3, 2.4) 5.1 (95%CI 3.1, 8.4) 0.9 (95%CI 0.6, 1.3) 1.2 (95%CI 0.8, 1.9) Pseudo- R^2 =0.47
SWE-05 Pedersen and Persson Waye (2007) Sweden	Sound pressure level (dB(A))	1.1 (1.02, 1.26)
	Noise sensitivity (not sensitive; sensitive)	2.5 (1.14, 2.53)
	Sound pressure level (dB(A)) General attitude (not negative; negative)	1.1 (1.00, 1.25) 13.4 (6.03, 29.59)
	Sound pressure level (dB(A)) Visual attitude (not negative; negative)	1.1 (1.01, 1.25) 14.4 (6.37, 32.44)
NL-07	Noise sensitivity (4-point scale)	1.94 (1.51, 2.49)

Study	Variables included in univariate or multiple logistic regression models	ORs for annoyance from wind turbines (95% CI) ^a
Van den Berg et al. (2008) The Netherlands	General attitude (5-point scale)	3.18 (2.37, 4.26)
	Visual attitude (5-point scale)	4.10 (2.84, 5.91)
	Visual judgement (scale)	2.55 (1.74, 3.73)
	Utility judgement (scale)	1.68 (1.43, 2.47)
NL-07 Pedersen et al. (2009) The Netherlands	Sound pressure level (dB(A))	1.1 (1.04, 1.17)
	Noise sensitivity (5-point scale)	1.4 (1.08, 1.87)
	General attitude (5-point scale)	1.7 (1.23, 2.39)
	Visual attitude (5-point scale)	2.8 (1.84, 4.35)

Bolded values indicate statistically significant differences.

Abbreviations: OR = odds ratio; CI = confidence interval

^a Odds ratios and 95% CIs have been calculated from published beta coefficients and standard errors.

NB: where factors are grouped, they have been entered into a multiple logistic regression analysis together.

Association between annoyance and sleep and health outcomes

Four studies reported on associations between annoyance due to wind turbine noise, sleep quality and health outcomes. Shepherd et al. (2011) reported that noise annoyance (from traffic, neighbours or other sources, including wind turbines) was negatively correlated with health to a similar degree in those living within 2 km of wind turbines ($r=-0.31$, $p>0.05$) and those living 8 km or more from turbines ($r=-0.26$, $p<0.001$). There were poor response rates in both the turbine and comparison groups (34% and 32% respectively), although this should not greatly affect measures of association within each group.

Pedersen (2011) assessed the relationship between annoyance with wind turbine noise (outdoors and indoors) and health outcomes in the two Scandinavian studies (SWE-00, SWE-05) and one Dutch study (NL-07). Annoyance outdoors was consistently associated with sleep interruption (Table 26), while two out of the three studies also showed a relationship between annoyance and headaches or irritability. One study demonstrated a paradoxical relationship between outdoor annoyance and reduced odds of self-reported tinnitus, but increased odds of self-reported diabetes or being tense and stressed (Table 26). This, and the lack of effect in the other studies, suggests that the results have been affected by confounding or chance. Annoyance indoors was consistently associated with sleep interruption, but other outcomes such as self-reported diabetes, headache, undue tiredness, being tense and stressed, and irritability were all associated with annoyance indoors in only one out of three studies (

Table 27). The cross-sectional design is ambiguous with respect to the direction of any of these associations; for example, it cannot distinguish between sleep interruption consequent on annoyance or annoyance consequent on sleep interruption. Similarly, the analyses that were undertaken in these studies do not account for all plausible confounders so it is unclear whether factors other than annoyance with wind turbine noise were responsible for the apparent association with sleep interruption.

Table 26 Association between annoyance outdoors due to wind turbine noise and health outcomes

Study	Self-reported health outcomes	SWE-00 ^a OR (95%CI) N ^c =319–333	SWE-05 ^a OR (95%CI) N ^c =720–744	NL-07 ^b OR (95%CI) N ^c =639–678
Comparison of studies NL-07, SWE-00 and SWE-05 Pedersen (2011) The Netherlands and Sweden	Sleep interruption	2.26 (1.76, 2.90)	1.71 (1.35, 2.17)	1.78 (1.49, 2.14)
	Chronic disease	0.90 (0.71, 1.08)	0.90 (0.74, 1.26)	0.98 (0.81, 1.19)
	Diabetes	0.69 (0.55, 1.22)	0.71 (0.40, 1.28)	1.70 (1.14, 2.56)
	High blood pressure	0.82 (0.55, 1.22)	1.10 (0.84, 1.45)	0.86 (0.64, 1.17)
	Cardiovascular disease	1.07 (0.58, 1.98)	1.00 (0.64, 1.55)	0.95 (0.65, 1.38)
	Tinnitus	1.55 (0.95, 2.53)	0.88 (0.60, 0.98)	0.82 (0.45, 1.48)
	Impaired hearing	1.03 (0.96, 1.19)	0.78 (0.51, 1.21)	1.13 (0.76, 1.67)
	Headache	1.24 (1.01, 1.51)	1.04 (0.86, 1.26)	1.25 (1.04, 1.50)
	Undue tiredness	1.22 (1.00, 1.49)	1.12 (0.93, 1.35)	1.10 (0.93, 1.31)
	Tense and stressed	1.25 (1.00, 1.56)	1.22 (1.00, 1.50)	1.27 (1.07, 1.50)
	Irritable	1.36 (1.10, 1.69)	1.22 (1.00, 1.49)	1.27 (1.07, 1.50)

Bolded values indicate statistically significant differences.

Abbreviations: OR = odds ratio; CI = confidence interval

^a Adjusted for age, gender, and estimated A-weighted sound pressure levels.

^b Adjusted for age, gender, economic benefits, and estimated A-weighted sound pressure levels.

^c Range of number of respondents in the analyses. Differences in number of respondents are due to missing cases, that is, the respondents not answering single questions in the questionnaire.

Table 27 Association between annoyance indoors due to wind turbine noise and health outcomes

Study	Self-reported health outcomes	SWE-00 ^a OR (95%CI) N ^c =319–333	SWE-05 ^a OR (95%CI) N ^c =720–744	NL-07 ^b OR (95%CI) N ^c =639–678
Comparison of studies NL-07, SWE-00 and SWE-05 Pedersen (2011) The Netherlands and Sweden	Sleep interruption	2.62 (1.90, 3.61)	2.58 (1.79, 3.71)	2.03 (1.66, 2.47)
	Chronic disease	0.93 (0.69, 1.25)	0.94 (0.68, 1.31)	1.05 (0.09, 1.28)
	Diabetes	0.73 (0.30, 1.75)	0.59 (0.22, 1.59)	1.62 (1.10, 2.40)
	High blood pressure	0.07 (0.36, 1.19) ^d	0.85 (0.52, 1.38)	0.83 (0.59, 1.16)
	Cardiovascular disease	0.99 (0.46, 2.17)	0.97 (0.49, 1.94)	0.76 (0.47, 1.22)
	Tinnitus	1.25 (0.77, 2.05)	0.57 (0.24, 1.33)	0.67 (0.28, 1.57)
	Impaired hearing	1.14 (0.72, 1.79)	0.56 (0.24, 1.32)	1.20 (0.80, 1.80)
	Headache	1.07 (0.83, 1.37)	1.11 (0.81, 1.52)	1.28 (1.06, 1.54)
	Undue tiredness	1.36 (1.05, 1.77)	1.00 (0.95, 1.80)	1.15 (0.96, 1.37)
	Tense and stressed	1.03 (0.79, 1.35)	1.07 (0.77, 1.48)	1.24 (1.04, 1.48)
	Irritable	1.22 (0.93, 1.61)	1.23 (0.80, 1.72)	1.26 (1.06, 1.50)

Bolded values indicate statistically significant differences.

Abbreviations: OR = odds ratio; CI = confidence interval

^a Adjusted for age and gender.

^b Adjusted for age, gender, and economic benefits.

^c Range of number of respondents in the analyses. Differences in number of respondents are due to missing cases, that is, the respondents not answering single questions in the questionnaire.

^d OR and 95% CI as printed in Pedersen 2011.

Multivariate analysis

Pedersen et al. (2009) used a multiple logistic regression model to simultaneously examine associations between estimated A-weighted SPL, economic benefit, visibility of wind turbines and area type with annoyance, using the response variable 'not annoyed / annoyed by the wind turbine sound' (Table 28).

Visibility of wind turbines, economic benefit from wind turbines and type of area of residence were strongly associated with reported annoyance from wind turbine noise. These associations were of greater magnitude than the association between estimated SPL and annoyance, meaning that these other factors had more impact on reported noise annoyance than the actual noise level. However, the weak association between estimated SPL and noise annoyance remained even after controlling for economic benefit, turbine visibility and area type (Table 28; Pedersen et al. 2009).

Receiving an economic benefit from wind turbines *reduced* the odds of being annoyed by wind turbine noise by more than 10 times, and living in a rural area near a main road reduced the odds by two-thirds, compared with living in a rural area without a main road. It should be noted that benefiting economically did not influence the *perception* of the sound, whereas estimated SPL, wind turbine visibility and living near a main road did influence perception (Pedersen et al. 2009).

Table 28 Independent predictors of annoyance from wind farms in the Dutch study (NL-07)

Study	Independent predictors	Odds ratios for annoyance from wind turbines ^a
NL-07 Van den Berg et al. (2008) The Netherlands	Age (OR per year) ^b Gender (male; female) ^b Economic benefits (no; yes) ^b	OR=1.03 (95%CI 1.01, 1.05) OR=0.93 (95%CI 0.56, 1.53) OR=0.05 (95%CI 0.01, 0.19)
NL-07 ^c Pedersen et al. (2009) The Netherlands n=639–678	Sound pressure level (dB(A)) Economic benefit (no; yes) Visibility (no; yes) Area type (reference: rural) Rural Rural with main road Built-up	OR 1.14 (95%CI 1.08, 1.20) OR 0.06 (95%CI 0.02, 0.23) OR 13.7 (95%CI 3.2, 59.0) OR 1.00 OR 0.34 (95%CI 0.17, 0.71) OR 1.92 (95%CI 1.02, 3.59)

Bolded values indicate statistically significant differences.

Abbreviations: OR = odds ratio; CI = confidence interval

^a Beta coefficients and standard errors have been used to transform to odds ratios and 95% CIs.

^b Adjusted for estimated sound pressure levels.

^c All listed determinants were included as independent predictors in a multivariate logistic regression and thus the reported odds ratios control for the effects of the other predictors in the model.

SQ3. IS THERE ANY RELIABLE EVIDENCE OF AN ASSOCIATION BETWEEN INFRASOUND AND LOW-FREQUENCY NOISE FROM WIND TURBINES AND ADVERSE HEALTH EFFECTS?

There were no studies obtained in the systematic review searches that reported specifically on infrasound and low-frequency noise exposures from wind turbines.

SUMMARY: DIRECT EVIDENCE ON NOISE

SQ1. Is there any reliable evidence of an association between distance from wind turbines and adverse health effects?

SQ2. Is there any reliable evidence of an association between audible noise (greater than 20 Hz) from wind turbines and adverse health effects?

SQ3. Is there any reliable evidence of an association between infrasound and low-frequency noise from wind turbines and adverse health effects?

Seven cross-sectional studies reported on the association between estimated noise levels or distance from wind turbines and self-reported adverse health effects. Their cross-sectional design means that it is not certain, or not known, whether onset of any possible adverse health effect preceded or followed the beginning of a participant's exposure to wind turbines. Four of the seven studies sought to mask participants to the intent of the research (i.e. investigating the effects of wind farms on humans) but it is not known whether this was effective. Response rates varied from 32% to 68% of potential participants contacted. Low response rates could have biased survey results (selection bias); for example, those near wind turbines and suffering from a health problem might have been more likely to respond, particularly if the intent of the study was evident. One study (Krogh et al. 2011), which lacked a systematic recruitment method and encouraged people with health problems to participate, would have been particularly prone to bias. Three studies used validated questionnaires in common use but supplemented them with author-developed items (NL-07; Nissenbaum, Aramini & Hanning 2012; Shepherd et al. 2011), while the other studies used questionnaires that were either author-developed or of uncertain origin. The validity of these other questionnaires is not known. Given these limitations, the findings of these studies should be interpreted cautiously.

Six studies reported on self-assessments of physical health problems (i.e. general health, any chronic disease, diabetes, high blood pressure, cardiovascular disease, tinnitus, hearing impairment, migraine and headache) and whether respondents had approached a doctor. Single studies showed associations between estimated A-weighted sound pressure levels and self-reported tinnitus or diabetes, but these findings were not replicated in other studies. Findings were not adjusted for all possible confounders and could also have been due to chance effects (as a consequence of conducting multiple statistical tests). None of the other physical health conditions were significantly associated with wind turbine exposure, whether assessed by proximity of a residence to a wind turbine or by estimated wind turbine sound pressure level at a residence.

SUMMARY (CONT.)

Five studies assessed the relationship between estimated wind turbine noise exposure and indicators of mental health. In only one of the five studies (Nissenbaum, Aramini & Hanning 2012) was greater proximity to wind turbines associated with poorer self-reported mental health. Respondents in this study were not masked to the intent of the study (at risk of recall bias).

Chance, bias and confounding are possible explanations for the few observed positive associations between physical and mental health and exposure to wind turbines.

The relationship between distance from wind turbines and quality of life was assessed by three studies. One study (Shepherd et al. 2011) that attempted to mask participants to study intent and used a validated questionnaire reported a positive association between distance from wind turbines and overall quality of life. The other two studies used author-formulated questions and did not mask the intent of the study and found similar results. One study found that the majority of people reported that their quality of life had altered since living within 2400 metres of a wind turbine (Krogh et al. 2011), while the remaining study reported a 74% difference in those wishing to move from the vicinity of a turbine (less than 1.4 km) when compared with residents living further away (over 3 km) (Nissenbaum, Aramini & Hanning 2012). Bias and confounding are possible explanations for the observed associations.

Aspects of self-reported sleep were recorded in all seven studies. Most of the studies were consistent in reporting poorer sleep (predominantly sleep interruption and poorer sleep quality) with greater estimated exposure to audible noise or shorter residential distance from wind turbines. No objective measures of sleep quality were used and possible confounding was not consistently controlled. In the SWE-00, SWE-05 and NL-07 studies the association of objective estimates of *sound pressure* level with sleep interruption was not as strong as the associations of subjective *annoyance with wind turbine noise* and sleep interruption.

Annoyance is not a health outcome but was considered relevant to this review due to its association with stress, which is a possible mediator or moderator of health outcomes. Four studies examined the association between annoyance and wind turbine noise. Noise was measured as estimated sound pressure level or distance from wind turbines. The studies were consistent in observing that annoyance was greater when noise level was greater or distance to a wind turbine was less. This association persisted, although it was weaker, after taking account of possible confounding between exposure to wind turbines and age, gender, economic benefit from wind turbines, visibility of wind turbines and type of area of residence.

SUMMARY (CONT.)

The association between estimated noise level and annoyance was significantly affected by the individuals' visual attitude to wind turbines (i.e. whether they found them beautiful, or ugly and unnatural) in the three studies that assessed this as a potential confounding or modifying factor.

Visual attitude to wind turbines was a much stronger predictor of annoyance than estimated sound pressure level. Bias and confounding are possible explanations for the associations observed between exposure to wind turbines and annoyance.

Is there any reliable evidence of an association between annoyance from wind turbines and adverse health effects?

Three cross-sectional studies that attempted to mask participants to study intent provided evidence on the association between annoyance from wind turbines and self-reported health, adjusting for estimated audible noise exposure (and age, gender and economic benefit from wind turbines in one study). Annoyance indoors and outdoors was consistently positively associated with sleep interruption but bias and confounding are possible explanations for this association. Less consistent effects were shown for the association between outdoor annoyance and headaches or irritability (two studies), or self-reported diabetes, being tense and stressed, or reduced odds of self-reported tinnitus (one study apiece). This lack of consistency was also shown for the association between indoor annoyance and self-reported diabetes, headaches, undue tiredness, being tense and stressed, and irritability (one study apiece).

There were no studies available that specifically reported on the association between adverse health effects and infrasound and low-frequency noise measured near wind turbines.

A summary of the evidence-base informing the association between estimated noise exposure from wind farms and health outcomes is given in Box 3.

Box 3 Evidence statement matrix for noise

Key question: Is there any reliable evidence of an association between audible noise (greater than 20 Hz) from wind turbines and adverse health effects? If so: A. How strong is this association? B. How does the strength of this association relate to <u>distance</u> from wind turbines? <i>[Systematic Review question on distance has been merged here]</i> C. Might this association be explained by: i. chance? ii. bias? or iii. confounding?			Bakker et al. (2012); Nissenbaum, Aramini and Hanning (2012); Pedersen and Persson Waye (2004), (2007); Krogh et al (2011); Morris (2012); Shepherd et al. (2011)		
1. Evidence-base (Number of studies, level of evidence and risk of bias and confounding in the included studies)					
7 level IV aetiology studies (cross-sectional studies)	A	One or more level I studies with a low risk of bias or several level II studies with a low risk of bias and confounding			
	B	One or two level II studies with a low risk of bias or SR/several level III studies with a low risk of bias and confounding			
	C	One or two level III studies with a low risk of bias or level I or II studies with a moderate risk of bias and confounding			
	D	Level IV studies or level I to III studies/SRs with a high risk of bias and confounding			
2. Consistency (If only one study was available, rank this component as 'not applicable')					
No associations between wind turbine exposure and physical or mental health effects were consistently reported in multiple studies. All three studies that reported on it found an association of wind turbine exposure with poorer quality of life, but only one study used a validated questionnaire and masked the intent of the study from participants. All four studies that examined it reported that wind turbine exposure was associated with interrupted or poorer sleep. All four studies that examined it, reported an association of wind turbine exposure with annoyance—the intent of three of these studies was masked from participants. Selection bias and confounding are possible explanations for these associations.	A	All studies consistent—for one relevant non-health effect (annoyance) and one health related effect (sleep disturbance/sleep quality)			
	B	Most studies consistent and inconsistency can be explained			
	C	Some inconsistency, reflecting genuine uncertainty around question—for one health related effect (quality of life)			
	D	Evidence is inconsistent—for all reported health effects			
	NA	Not applicable (one study only)			

3. Population health impact <i>(Indicate in the blank space below if the study results varied according to some unknown factor (not simply study quality or sample size) and thus the population health impact of the exposure could not be determined; or whether the impact could not be determined because the studies were underpowered and could not be meta-analysed. Otherwise, provide justification for your selection of the A–D rating, i.e. the size of the effect and precision of the estimate of adverse health effects)</i>		
The very limited evidence of any impact of wind turbine exposure on self-reported physical and mental health effects could be explained by chance, bias or confounding. While the evidence for effects of wind turbine exposure on sleep and quality of life was inconsistent and possibly explained by bias or confounding, the associations observed suggest the possibility of a moderate impact on exposed people. While there was consistent evidence of an association between wind turbine exposure and annoyance, the association was weak when adjusted for plausibly confounding variables. Thus any health-related impact of annoyance, if there is one, would probably be small.	A	Very large
	B	Substantial
	C	Moderate—for health-related effects (sleep disturbance/sleep quality and quality of life)
	D	Slight/restricted—for health effects and a relevant non-health effect (annoyance)
4. Generalisability <i>(How well does the body of evidence match the population being targeted by the NHMRC advice?)</i>		
Poor response rates. Unknown whether responders are similar to non-responders and thus representative of all residents near wind farms.	A	Evidence directly generalisable to target population
	B	Evidence directly generalisable to target population with some caveats
	C	Evidence not directly generalisable to the target population but could be sensibly applied
	D	Evidence not directly generalisable to target population and hard to judge whether it is sensible to apply
5. Applicability <i>(Is the body of evidence relevant to the Australian setting for the exposure?)</i>		
One study was done in Australia. Remaining studies were done in New Zealand, Canada, USA, The Netherlands, and Sweden (two studies). Since European and North American countries have a longer history of, and more extensive, wind turbine development and a greater population density than Australia, it is possible that wind turbine exposure in Australia is qualitatively and quantitatively different from the exposures contributing most evidence.	A	Evidence directly applicable to Australian exposure setting
	B	Evidence applicable to Australian healthcare exposure setting with few caveats
	C	Evidence probably applicable to Australian exposure setting with some caveats
	D	Evidence not applicable to Australian exposure setting
Other factors <i>(Indicate here any other factors that you took into account when assessing the evidence-base (e.g. issues that might cause the group to downgrade or upgrade the recommendation, such as the biological plausibility evidence presented in Background Question 4)</i>		

No studies in the systematic review specifically reported on the health impact of infrasound and low frequency noise (ILFN). Estimates of A-weighted audible wind turbine sound at subjects' residences and distance of residences from wind turbines probably misclassify exposure to infrasound from wind turbines and studies based on them might, therefore, under-estimate the strength of any associations of wind turbine infrasound with health effects that might be present.

The information addressing Background Questions 3 and 4 (see relevant sections in the report) was not sufficiently persuasive to result in an upgrade of the evidence rating obtained from the direct evidence. A mechanism of action for ILFN to cause adverse health effects could not be identified. The effect of infrasound in laboratory circumstances was based on the measurement of intermediate physiological outcomes and produced inconsistent findings of uncertain applicability to the wind turbine setting.

The quality of the evidence-base and the evidence for direct health effects were given greatest weight when formulating the overall rating.

EVIDENCE STATEMENT MATRIX

Please summarise the synthesis of the evidence relating to the key question, taking all the above factors into account.

Component	Rating	Description
1. Evidence-base	D	7 level IV studies with a high risk of bias and confounding
2. Consistency	D A C	Evidence is inconsistent—for health effects All studies consistent—for one relevant non-health effect (annoyance) and one health related effect (sleep disturbance/sleep quality) Some inconsistency, reflecting genuine uncertainty around question—for one health related effect (quality of life)
3. Population health impact	D C	Very limited evidence for any health effects and an apparently very weak effect of annoyance, after adjustment for plausible confounding, are consistent with slight population health impact While associations of wind turbines with poorer sleep and quality of life are uncertain, if real, their impacts on the exposed population would probably be moderate
4. Generalisability	D	Evidence not directly generalisable to target population and hard to judge whether it is sensible to apply
5. Applicability	C	Evidence probably applicable to Australian exposure setting with some caveats

Evidence statement

There is no consistent evidence that noise from wind turbines—whether estimated in models or using distance as a proxy—is associated with self-reported human health effects. Isolated associations may be due to confounding, bias or chance.

There is consistent evidence that noise from wind turbines—whether estimated in models or using distance as a proxy—is associated with annoyance, and reasonable consistency that it is associated with sleep disturbance and poorer sleep quality and quality of life. However, it is unclear whether the observed associations are due to wind turbine noise or plausible confounders.

Evidence rating

D

Parallel evidence

BQ4. IS THERE BASIC BIOLOGICAL EVIDENCE, OR EVIDENCE FROM RESEARCH INTO OTHER CIRCUMSTANCES OF HUMAN EXPOSURE TO NOISE EMISSIONS, THAT MAKE IT PLAUSIBLE THAT WIND TURBINES CAUSE ADVERSE HEALTH EFFECTS?

Audible noise at high levels has been shown to disrupt sleep and cause hearing impairment and other health problems. Internationally, the environmental burden of disease due to environmental noise has been the focus of extensive study (WHO 2011). A common approach in this research has been through quantitative risk assessment³⁴. The working group of the WHO European Centre for Environment and Health estimated the annual burden of disease in the European Union due to audible noise based on the following endpoints (WHO 2011):

- cardiovascular disease;
- cognitive impairment;
- sleep disturbance;
- tinnitus; and
- annoyance³⁵.

The working group noted for each of these endpoints that:

1. in recent years the evidence from epidemiological studies of association between exposure to noise from road traffic and aircraft and ischaemic heart disease and hypertension has increased. Road traffic noise has been shown to possibly increase the risk of both these diseases, albeit the confidence intervals of pooled effects from meta-analyses did not rule out chance effects. Very few studies on the cardiovascular effects of exposure to rail traffic noise are available;
2. the extent to which noise impairs cognition, particularly in children, has been the subject of experimental and epidemiological studies;
3. in epidemiological studies, self-reported sleep disturbance is the most commonly used and accessible outcome indicator because the alternative method—electrophysiological measurement—is costly, difficult to conduct for large samples, and may be a sleep-influencing factor (i.e. a source of bias);
4. the study of tinnitus³⁶ due to excessive noise has a long history, with 50–90% of patients exposed chronically to high noise levels reporting tinnitus. In some people, tinnitus can cause sleep disturbance, effects on cognition, communication problems, anxiety, depression, psychological distress, frustration, tension, irritability, inability to work, reduced efficiency and restricted participation in social activities; and

³⁴Risk assessment refers to hazard identification, the assessment of population exposure and the determination of appropriate exposure–response relationships (WHO 2011).

³⁵Annoyance was selected for burden of disease estimation in consideration of the WHO definition of health as ‘a state of complete physical, mental and social wellbeing and not merely the absence of disease’ (WHO 1948).

³⁶Tinnitus is the conscious perception of sound in the absence of an external source (Elgoyhen & Langguth 2010).

5. high levels of annoyance due to environmental noise can be considered as an environmental health burden, which can be assessed using standardised questionnaires (WHO 2011).

The Regional Office for Europe of the WHO has also conducted extensive research into the effects of audible environmental noise during the night hours, with an emphasis on sleep and the downstream effects of sleep disturbance (WHO 2009). In order to inform guidelines on night noise in Europe, the WHO Environment and Health working group selected a number of health-related endpoints in order to categorise evidence of association between those endpoints and night noise as either 'sufficient' or 'limited'. Definitions for the terminology as applied by the working group are provided in Table 29.

The WHO working group concluded that there is sufficient evidence that night noise is related to self-reported sleep disturbance, use of pharmaceuticals, self-reported health problems and insomnia-like symptoms. These effects can lead to a considerable burden of disease in the population. For other effects including hypertension, myocardial infarction and depression, limited evidence was found. Although these studies were few or not conclusive, a biologically plausible pathway could be constructed from the evidence. The remaining key conclusions from the working group were that (WHO 2009):

- sleep is a biological necessity and disturbed sleep is associated with a variety of adverse health effects;
- there is *sufficient* evidence that night noise exposure causes self-reported sleep disturbance, increased medicine use, increased body movements and insomnia;
- while sleep disturbance due to noise is viewed as a health issue in itself (insomnia), it leads to downstream consequences for health and wellbeing;
- there is *limited* evidence that disturbed sleep from night noise causes fatigue, accidents and reduction in performance; and
- there is *limited* evidence that noise at night causes changes in hormonal levels and clinical conditions such as cardiovascular disease, depression and other mental illness (plausible biological model available with *sufficient* evidence for elements of the causal chain).

Table 29 Definitions of 'sufficient' and 'limited' evidence as per the WHO working group of the European Centre for Environment and Health

'Sufficient' evidence	'Limited' evidence
A causal relationship has been established between exposure to noise and a health effect. In studies where coincidence, bias and distortion could reasonably be excluded, the relationship could be observed. The biological plausibility of the noise leading to the health effect is also well established.	A relationship between the noise and the health effect has not been observed directly, but there is available evidence of good quality supporting the causal association. Indirect evidence is often abundant, linking noise exposure to an intermediate effect of physiological changes which lead to the adverse health effects.

Source: WHO (2009)

The health effects of noise within the audible range, especially from road traffic³⁷, have been extensively studied. However, extrapolation of these findings to the wind farm context is not simple. As distance is highly correlated with estimated SPL (van den Berg et al. 2008) it is not expected that substantial audible noise exposures (>45 dB(A)) would be associated with modern wind turbines at distances of more than about 280 m, although this might vary by terrain, type of wind turbine and wind conditions (Ellenbogen et al. 2012); see page 68 for further information. Sleep disturbance from noise exposure alone is not plausible at noise levels of 30 dB(A) and below, and has only modest effects at 30-40 dB(A) (WHO 2011).

ILFN is made up of long waves, while moderate to high frequency noise consists of relatively short waves. Noise at high frequency (pitch) attenuates in intensity (loudness) over much shorter distances and does not pass easily through doors and windows, unlike ILFN which can more easily pass through these obstacles. Hearing becomes gradually less sensitive as frequency decreases, so for humans to perceive infrasound and low frequencies, the SPL needs to be high. Indoors, room resonances can *increase* SPLs and lead to variations of SPL inside a room for low frequency noise (Persson Waye 2004; Roberts & Roberts 2009).

ILFNs are, therefore, the exposures of most relevance at the range of distances typically observed between residential dwellings and commercial wind turbines (see 'Noise' section, page 59).

The parallel evidence identified for Background Question 4 concerning the effects of ILFN on human health is summarised in Table 30. This parallel evidence involved the experimental exposure of human subjects to ILFN produced in a laboratory setting. Systematic measurement of biological or psychological variables before, during or after the ILFN exposure was undertaken, and/or in relation to periods of non-exposure as well as periods of exposure. This evidence was used to address the biological plausibility that wind farms could cause adverse health effects. The specific limitations of each of the studies are also stated.

Infrasound and low-frequency noise

In this section ILFN will be considered to be sound composed mainly or exclusively of frequencies below 250 Hz.

The ILFN exposure produced in the available laboratory studies was frequently greater than (usually A-weighted) 80 dB and ranged between 40 and 144 dB. The impact of ILFN on the measured outcomes was largely inconsistent and inconclusive (Table 30). Mainly intermediate outcomes, including physiological changes such as heart rate, cortisol level, respiratory rate and blood pressure, were considered in the available studies (Alford et al. 1966; Danielsson & Landstrome 2009; Fuchs, Verzini & Nitardi 1995; Mills et al. 1983; Takigawa, Sakamoto & Murata 1991; Verzini et al. 1999; Waye et al. 2002, 2003). Health outcomes were not considered. The data suggest that low-frequency noise at high SPLs may elicit a temporary threshold shift (TTS) in hearing (Alford et al. 1966; Mills et al. 1983) and lead to statistically significant, albeit small and

³⁷The majority of environmental noise discussed previously in this section was from road traffic (WHO 2011).

inconsistent, changes in systolic and diastolic blood pressure, and pulse or heart rate, which are of uncertain significance to health. Other outcomes studied included subjectively measured endpoints such as anxiety, mood and sleep disturbance. Studies of exposure from non-wind-turbine sources investigating a plausible relationship between ILFN and health generally did not present sufficient data to assess similarities or differences between exposed and non-exposed groups of individuals. The studies were of small sample size, and so a reasonably even distribution of potential confounders could not be assured in parallel study designs or pre-test/post-test designs (4 of 8 studies). Neither of these was an issue for the other four studies because each subject in all exposures was their own control. There were not enough studies reporting on exactly the same intervention or outcomes to address the 'replicability' criterion for causation (modified Bradford Hill Guidelines, see Table 5). Finally, there was inconsistency across the studies with respect to the influence of infrasound on physiological measures, and so the available evidence did not meet the 'similarity' criterion.

Table 30 Parallel evidence examining the association between infrasound and low-frequency noise (ILFN) and adverse health effects

Study	Design	Exposure	Outcome	Limitations
Fuchs, Verzini and Nitardi (1995)	Randomised controlled trial (RCT) n=25 university students (aged 18–25 years) randomly assigned to 5 groups (four ‘experimental’ arms corresponding to different levels of ILFN and one ‘control’ group). To simulate infrasonic noise environments, with high levels of infrasound, a pressure chamber was built by the investigators (optimal operation range: 10–80 Hz).	30-minute exposure to ILFN conditions: 10 Hz/110 dB, 20 Hz/97 dB, 40 Hz/89 dB and 80 Hz/68 dB followed by 10 minutes without sound stimulus. Levels were fixed at approximately 25 dB over Vercammen's mean auditory thresholds.	Mean hearing thresholds, physiological parameters, corporal sensations, annoyance or degree of ‘agreeability’ measured.	Small sample size (particularly spread across 5 groups). Longer time spent in exposure to ILFN (30 minutes) group compared with that in the no-exposure group (10 minutes).

Results

ANOVA for repeated measurements on heart rate (dependent variable) and experimental condition (independent variable)

<i>F</i> -statistic	p value
4.96	0.038

Note: the *F*-statistic is for the difference between HR1 (‘first difference of heart rate’) and HR2 (‘second difference of heart rate’); ‘first’ denotes the difference between heart rate registered before noise exposure and the last measurement registered during exposure, while ‘second’ denotes the difference between the last measurement registered during exposure and the last measurement registered after the 10-minute period without sound stimulus.

Summary

There were no statistically significant differences in physiological variables between the groups reported from this study. While heart rate HR1 was statistically

Study	Design	Exposure	Outcome	Limitations
significantly higher than HR2, this difference relates to variation in heart rate over time in the experiment, rather than variation between groups.				
Verzini et al. (1999)	RCT n=22 students (aged 18–25 years) assessed for normal hearing, randomly allocated to 3 exposure phases (1-week interval between phases).	Phase 1: 15 minutes of quiet preceding 30-minute exposure to 10 Hz/110 dB tone, followed by 15 minutes of quiet. Phase 2: 15 minutes of quiet preceding 30-minute exposure to a boiler noise (1/3 octave band centred on 10 Hz, level 105±2 dB followed by 15 minutes of quiet. Phase 3: control phase—60 minutes without sound stimulus exposure.	Physiological endpoints: heart and respiratory rates, peripheral temperature and galvanic skin exposure. Subjective assessment of responses (see 'Results' for further details).	Only significant results concerned the subjective mood-based measures, not the objective physiological endpoints. Subjective outcomes are more prone to bias if an individual is not masked to study intent and has strong prior beliefs.

Study	Design	Exposure	Outcome	Limitations
Results				
No statistically significant differences in the physiological parameters were observed.				
<i>ANOVA for subjective assessments with experimental condition as the grouping factor and subjective responses as dependent variables</i>				
Scales	<i>F</i> -statistic	p value		
Agreeable/disagreeable	25.45	p≤0.001		
Beneficial/harmful	41.02	p≤0.001		
Pleasant/unpleasant	8.56	p≤0.001		
Acceptable/unacceptable	6.02	p≤0.005		
Strong/weak	3.42	p≤0.043		
Shrill/soft	5.44	p≤0.008		
Arousing/drowsy	10.49	p≤0.001		
Exciting/calm	9.41	p≤0.001		
Soothing/startling	21.03	p≤0.001		
Concentrating/distracting	22.35	p≤0.001		
Harmonious/non-harmonious	20.87	p≤0.001		
Summary				
There were no statistically significant differences among the exposure conditions for any of the physiological variables measured (means or other summary parameters were not reported for the physiological experiments). However, each exposure condition was statistically significantly associated with each subjective response; these subjective assessments were, in each case, more adverse under each noise exposure condition than under the control condition.				

Study	Design	Exposure	Outcome	Limitations
Takigawa, Sakamoto and Murata (1991)	Cross-over RCT to study impact of infrasound on: eye movement (n=25 healthy males, aged 22–24 years); body sway (n=34 healthy males, aged 21–24 years); pulse-wave (n=9 healthy males and females aged 25–55 years).	The subjects were exposed to two kinds of sound: wide octave band noise (frequency range: 100–10,000 Hz); narrow band infrasound (frequency range: 3–7 Hz). Noise intensity was 95 dB(A) and 70 dB(A), while the SPL of the infrasound was 95 dB. Order of exposure to the different kinds of sound was randomly assigned.	(1) Amplitude of involuntary eye movement (subject's eyes first open and then closed for 45 seconds). (2) Body sway was measured as movement from the centre of gravity of a subject in a standing position by using the regular triangle platform method. (3) Pulse-wave recording was made continuously under pre-exposure conditions for 1 minute, during exposure to either of the sounds for 3 minutes, and finally under post-exposure conditions for 1 minute.	The applicability of these findings, from an acute exposure setting to the chronic exposure setting, where acclimatisation might be expected (as in wind farm setting), is unknown.

Results

With the exception of p values, all data were presented graphically and cannot be reproduced in this table. A narrative summary is provided below.

Summary

Eye movement: Eyes open—no significant differences in the amount of total amplitude observed between pre-exposure and the other exposure conditions. Eyes closed—the amount of total amplitude was higher in the infrasound exposure phase compared with the pre-exposure phase ($p < 0.025$), and not significantly different between the noise exposure and the pre-exposure phase.

Body sway: No statistically significant differences between exposure and pre-exposure periods for wide octave band noise. Significant reduction in body sway

Study	Design	Exposure	Outcome	Limitations
(less than 1% difference) in high frequency band of infrasound between pre-exposure and exposure conditions (p<0.05). <u>Pulse wave</u>: Pulse wave height was statistically significantly reduced upon either exposure compared with pre-exposure (p<0.01). The authors suggested that observed effects from infrasound resulted from an impact on the vestibular reflex. Wide octave band noise had no observed effect on eye movement and body sway, although the pulse-wave was changed by exposure.				
Waye et al. (2003)	Cross-over design Twelve male subjects slept for 5 consecutive nights in a noise-sleep laboratory. After one night of acclimatisation and one reference night, subjects were exposed to either traffic noise (TN) or low-frequency noise (LFN) on alternate nights. Exposure order was randomised.	TN (35 dB LA_{eq}, 50 dB LA_{max}) or LFN (40 dB LA_{eq}). LFN = frequency range of 31.5–125 Hz. Third octave band at 50 Hz was amplitude modulated with modulation frequency of 2 Hz.	Salivary-free cortisol concentration. Subjects also completed questionnaires on mood and sleep quality.	The authors stated that the study was hypothesis-generating. The exposure conditions were developed to resemble normal sleeping. Exposure represents acute exposure (after one night of acclimatisation) and may not be applicable to the wind turbine setting. There could have been previous exposure and adaptation to TN exposure, whereas the reaction to LFN might have been an alarm reaction.
Results				
<i>Median values of subjective sleep evaluations</i>				
	Reference night	TN	LFN	
Response variable ^a				
Recalled time to fall asleep (min)	20	35	39 ^b	
Morning feelings				

Study	Design	Exposure	Outcome	Limitations
Tense	3.0	4.3	4.0	
Irritated	2.8	4.6 ^b	4.2	
Afternoon feelings				
Tense	3.1	4.0	2.6	
Irritated	2.4	2.5	2.4	
Evening feelings				
Tense	3.2	1.8	2.4	
Irritated	1.9	1.6	2.4	
^a Subjective variables 'tense' and 'irritated' rated on a 0–10 scale with 10 indicating the highest degree of tension/irritability.				
^b p<0.05 P value for comparison with reference night				
<i>Pearson's correlation coefficients (r) between subjective response and cortisol levels at 30 and 45 minutes</i>				
	Cortisol level at 30 minutes			
	Cortisol level at 45 minutes			
	TN	LFN	TN	LFN
	r	p value	r	p value
Response variable:				
Sleep quality	−0.66	<0.05	−0.34	>0.10
Morning				
Tiredness	−0.53	0.08	−0.33	>0.10
Irritation	−0.21	>0.10	−0.44	>0.10
Activity	−0.23	>0.10	0.60	<0.05
Pleasantness	0.04	>0.10	0.59	<0.05
Summary				
Awakening cortisol response on the reference nights showed a normal cortisol pattern (as indicated by the graphical analysis not shown here). Subjects reported that they took longer to fall asleep during exposure to LFN than on reference night. The awakening cortisol response following exposure to LFN was attenuated at				

Study	Design	Exposure	Outcome	Limitations
30 minutes after awakening. Lower cortisol levels after awakening were associated with subjective reports of lower sleep quality and mood. Most notably, levels of cortisol had not peaked by 30 minutes post awakening after exposure to low-frequency noise, and these attenuated levels of cortisol were related to tiredness and negative mood. Exposure to traffic noise was observed to induce 'irritation'. Cortisol levels 30 minutes after awakening were related to sleep quality after exposure to traffic noise.				
Waye et al. (2002)	Cross-over study assessing impact of LFN on cortisol in 32 participants. Each participant took part in two test sessions, on separate days and always in the afternoon. Total average exposure time was 2 hours and 10 minutes. Proportion of subjects starting (non-randomised) with each of the two noise conditions was similar, 18/14 for LFN condition and 20/12 for the reference noise condition.	Two noises were used: reference noise (recorded from a ventilation installation, flat frequency); LFN (frequency range of 31.5–125 Hz) plus the ventilation noise, using a digitised sound processor system.	Subjective stress and annoyance; any resultant increase in cortisol secretion; influence of noise sensitivity on cortisol response.	Applicability: study set out to replicate office working conditions and the noises emitted from air-conditioning or ventilation systems. A 2-hour office work task performed in the afternoon may not produce the same effects as continuous exposure to LFN from wind turbines.

Study	Design	Exposure	Outcome	Limitations																								
Results <i>ANOVA for a 3-way interaction between salivary cortisol concentration, noise condition and sensitivity category</i> F-statistic p value 3.736^a 0.06^a ^a The authors reported these data for ‘the interaction between noise condition, <i>time period</i> and sensitivity’. Professor Persson Wayne clarified, upon being contacted, that ‘time period’ related to ‘cortisol concentration over time’.																												
Summary Higher cortisol levels (six saliva samples during the 2-hour exposure) were observed among the group with high sensitivity to noise under exposure to LFN (p=0.06). This difference could be due to chance.																												
Danielsson and Landstrom (2009)	Randomised cross-over trial assessing impact of acute infrasound on blood pressure, pulse rate and serum cortisol levels in 20 healthy male volunteers.	Varying sound frequencies (6, 12, 16 Hz) and pressure levels (95, 110, 125 dB(lin)) were tested.	Diastolic and systolic blood pressure; pulse rate; serum cortisol.	Process of randomisation not adequately described. Applicability of findings from a controlled experimental condition to wind turbine setting uncertain.																								
Results <i>Blood pressure (mmHg) and heart rate (beats/minute) during exposure to 125 dB infrasound at different frequencies and adjacent silent control periods, mean ± SE</i> <table><tr><td></td><td colspan="3">Frequency (Hz)</td></tr><tr><td></td><td>6</td><td>12</td><td>16</td></tr><tr><td>Diastolic blood pressure</td><td></td><td></td><td></td></tr><tr><td>Test</td><td>66.2±2.2</td><td>65.8±2.2</td><td>67.3±1.9</td></tr><tr><td>Control</td><td>65.9±1.9</td><td>66.4±2.1</td><td>66.3±2.3</td></tr><tr><td>Difference</td><td>0.3 (p<0.05)</td><td>−0.6 (NS)</td><td>1.0 (p=0.05)</td></tr></table>						Frequency (Hz)				6	12	16	Diastolic blood pressure				Test	66.2±2.2	65.8±2.2	67.3±1.9	Control	65.9±1.9	66.4±2.1	66.3±2.3	Difference	0.3 (p<0.05)	−0.6 (NS)	1.0 (p=0.05)
	Frequency (Hz)																											
	6	12	16																									
Diastolic blood pressure																												
Test	66.2±2.2	65.8±2.2	67.3±1.9																									
Control	65.9±1.9	66.4±2.1	66.3±2.3																									
Difference	0.3 (p<0.05)	−0.6 (NS)	1.0 (p=0.05)																									

Study	Design	Exposure	Outcome	Limitations
Systolic blood pressure				
Test	118.3±1.6	118.9±1.8	117.4±1.6	
Control	119.2±1.7	119.0±1.6	119.5±1.7	
Difference	−0.9 (NS)	−0.1 (p=0.05)	2.1 (p<0.01)	
Pulse rate				
Test	59.1±1.6	59.3±1.9	59.2±1.8	
Control	61.1±1.8	60.9±2.0	61.0±1.9	
Difference	−2.0 (p<0.01)	−1.6 (p<0.01)	−1.8 (p<0.01)	
<i>Blood pressure (mmHg) and heart rate (beats/min) during exposure to 16 Hz infrasound at different pressure levels and adjacent silent control periods, mean ± SE</i>				
	Exposure (dB)			
	95	110	125	
Diastolic blood pressure				
Test	71.8±1.5	70.8±1.5	71.3±1.5	
Control	70.4±1.5	70.8±1.5	71.8±1.5	
Difference	1.4 (p<0.05)	0.0 (NS)	−0.5 (NS)	
Systolic blood pressure				
Test	123±1.8	121.4±1.5	122.8±1.6	
Control	122.8±1.8	121.6±1.6	122.4±1.7	
Difference	−0.5 (NS)	−0.2 (NS)	0.4 (NS)	
Pulse rate				
Test	60.5±2.5	60.0±2.3	60.9±2.4	
Control	61.1±2.4	61.2±2.4	60.8±2.3	
Difference	−0.6 (NS)	−1.2 (p<0.01)	0.1 (NS)	

Study	Design	Exposure	Outcome	Limitations
Summary The data suggest statistically significant, albeit very small and inconsistent, changes in systolic and diastolic blood pressure and pulse rate. The authors note that acute infrasonic stimulation induces a peripheral vasoconstriction with increased blood pressure. There was no statistically significant change in serum cortisol levels (no data provided by authors).				
Alford et al. (1966)	Pre-post test design assessing impact of laboratory-induced LFN on extra-auditory function in 21 subjects.	3 minutes of repeated exposure to 119–144 dB / 2–12 Hz.	Temporary threshold shift (TTS) ^a ; breathing rate; nystagmus; vertigo; reaction performance time. ^a Exposure to impulse and continuous noise may cause only a temporary hearing loss. If a person regains hearing, the temporary hearing loss is called a temporary threshold shift.	The number of subjects was small. 5 subjects in the case series had some form of hearing loss. There was no control group.
Results The data showed TTS from 10 dB to 22 dB in 11 of 21 subjects after 3 minutes of repeated exposure to 119–144 dB / 2–12 Hz. The TTS was observed in the frequency range 3–8 kHz. There was a slight increase in breathing rate (4 breaths/minute). There were no effects of LFN on nystagmus, vertigo (vestibular effects), reaction performance time and heart rate. None of the subjects reported respiratory distress, palpitations or abdominal cramps. All subjects reported experiencing some pressure in their ears but only one reported tinnitus. No discomfort was experienced with regard to bodily vibration, disorientation, mental confusion, sensory decrement or post-exposure fatigue.				
Mills et al. (1983)	Pre-post test design examining impact of LFN on TTS in 52 subjects.	Subjects were exposed for 8 hours (SPL=90 dB(A)) or 24 hours (SPL=84 dB(A)) to an octave-band noise centred at 63, 125 or 250 Hz.	TTS	There are inadequate data presented in the paper to assess the validity of this study.

Study	Design	Exposure	Outcome	Limitations
Results Only an abstract was available. Summary TTSs of different degrees were observed depending on the frequency of the noise (octave-band noise, centred at 63, 125 or 250 Hz). After 24 hours of exposure to 84 dB(A), TTS from 7 dB to 15 dB in the frequency range 300–500 Hz was observed. An 8-hour-exposure to 90 dB(A) caused TTS from 12 dB to 17 dB in the frequency range 25–700 Hz. Although TTS was less than 20 dB, complete recovery for many of the subjects required as long as 48 hours.				

Abbreviations: RCT = randomised controlled trial; ILFN = infrasound and low-frequency noise; SPL = sound pressure level; TN = traffic noise; TTS = temporary threshold shift; ANOVA = analysis of variance; SE = standard error; dB = decibels; dB(A) = A-weighted sound pressure level (decibels); dB(lin) = unweighted sound pressure level (decibels); NS = not (statistically) significant

SUMMARY: MECHANISTIC AND PARALLEL EVIDENCE ON NOISE

BQ1. What are wind turbines and wind farms?

A wind turbine uses wind to produce electricity. There are two main types of wind turbine: the horizontal axis wind turbine (HAWT) and the vertical axis wind turbine (VAWT). HAWTs are more common because they are considered to be more efficient (Ali et al. 2011).

A group of wind turbines is known as a wind farm. A large wind farm may consist of several hundred individual wind turbines, cover a large geographical area and be located offshore or on land.

BQ2. By what specific physical emissions might wind turbines cause adverse health effects? (Noise)

Noise is defined as an unwanted sound or an unwanted combination of sounds. Sound is perceived and recognised by its loudness (sound pressure level, SPL) and pitch (frequency). The general range for human hearing for young adults is between 20 Hz and 20 kHz, with a declining upper limit with ageing (Berglund, Hassmen & Job 1996). Low-frequency sound definitions vary and can range from 20 Hz up to 100 Hz - 250 Hz. Sound <20 Hz is generally termed infrasound and is considered inaudible in normal environments. However, frequencies well below 20 Hz can be audible if the amplitude of the SPL is high enough.

Aerodynamic noise is the major component of noise from modern wind turbines (Pedersen & Persson Waye 2004, 2007; van den Berg 2004). A key source of aerodynamic sound from modern wind turbines is the trailing edge noise that originates from air flow around the components of the wind turbine (blades and tower), producing a 'whooshing' sound in the 500–1000 Hz range (Hau 2008; Roberts & Roberts 2009). This is often described as amplitude (or aerodynamic) modulation, meaning that the sound can vary due to atmospheric effects and directional propagation effects (van den Berg 2004).

SUMMARY (Cont.)

BQ3. For each such emission, what is the level of exposure from a wind turbine and how does it vary by distance and characteristics of the terrain separating a wind turbine from potentially exposed people?

Numerous factors (e.g. meteorological conditions, wind turbine spacing, wake and turbulence effects, vortex effects, turbine synchronicity, tower height, blade length and power settings) can contribute to the wind turbine sound that is heard or perceived at residences. However, consistent with the inverse distance law, most wind turbine sound will dissipate as distance from the source increases.

Noise at high frequency lessens in intensity (loudness as measured by SPL) over much shorter distances than noise at lower frequency. It does not pass easily through doors and windows—unlike lower frequencies which can more easily pass through these obstacles. ILFN is, therefore, the exposure of most relevance at the range of distances typically observed between residential dwellings and commercial wind turbines. Hearing becomes gradually less sensitive as frequency decreases, so for humans to perceive ILFN, the SPL needs to be high.

Deriving a specific SPL from wind turbines in the presence of background noise is difficult. The 2013 South Australian EPA study (Evans, Cooper & Lenchine 2013) measured infrasound at urban and rural locations and compared these with measurements taken at residences near two wind farms. Levels of background noise at residences near the wind farms were also measured during organised turbine shutdowns. It was concluded that the level of infrasound at locations near wind farms was no greater than that experienced in other urban and rural environments. Further, the contribution of wind turbines to the measured infrasound levels taken at residences at a distance of approximately 1.5 km was insignificant in comparison with the background level of infrasound in the environment.

SUMMARY (Cont.)

BQ4. Is there basic biological evidence, or evidence from research into other circumstances of human exposure to physical emissions that wind turbines produce, that make it plausible that wind turbines cause adverse health effects?

The health effects of noise within the audible range, particularly from road traffic, are well known. However, extrapolation of these findings to the wind farm context is not simple. Given that distance is highly correlated with estimated SPL, it is not expected that substantial audible noise exposures (>45 dB(A)) would be associated with modern wind turbines at distances of more than about 280 m (Ellenbogen et al. 2012), although this might vary by terrain, type of wind turbine and wind conditions. Sleep disturbance from noise exposure alone is not plausible at noise levels of 30 dB(A) and below, and has only modest effects at 40 dB(A) and below (WHO 2011).

ILFN produced in the laboratory setting—with SPL typically greater than 80 dB but ranging between 40 and 144 dB in the available studies—appeared to have inconsistent and inconclusive physiological effects. Outcomes that were considered in these laboratory studies included changes in heart rate, cortisol level, respiratory rate and blood pressure. The data suggest that low-frequency noise at high SPLs may elicit a temporary threshold shift in hearing (Alford et al. 1966; Mills et al. 1983) and may lead to statistically significant, albeit very small and inconsistent, changes in systolic and diastolic blood pressure, and pulse or heart rate. Health outcomes were not studied. There were too few studies reporting on exactly the same intervention or outcomes to determine if the results were replicable, and where studies were similarly designed there were inconsistent findings with respect to whether or not ILFN influenced physiological measures.

SHADOW FLICKER

BQ2. BY WHAT SPECIFIC PHYSICAL EMISSIONS MIGHT WIND TURBINES CAUSE ADVERSE HEALTH EFFECTS?

Predicting the extent of shadow flicker from a wind turbine

Exposure to flicker from a turbine is determined by the hub height, blade diameter, height of the sun and blade direction relative to the observer, and these variables are affected by the time of day, time of year, wind direction and geographical location (Harding, Harding & Wilkins 2008; Verkuijlen & Westra 1984).

Ellenbogen et al. (2012) present a detailed discussion of how to estimate the maximum distance from a wind turbine that a shadow flicker will extend to. Briefly, this can be estimated using the following formula:

$$X_{shadow, max} = (H + R - h_{view}) / \tan(\alpha_s)$$

where H is the turbine height, R is the rotor radius, h_{view} is the height of the viewing point and α_s is the altitude of the sun.

Ellenbogen et al. (2012) report that ‘safe distances to reduce shadow flicker’ would depend on the specific nature of the project and the presence of residences or roadways and geographic layout. Forestry and existing shadows would diminish the nuisance from turbine-produced shadow flicker, whereas open-land areas (such as farmland) are more susceptible to flicker-induced annoyance.

Generally, a shadow flicker ‘risk zone’ would incorporate an impact area that is 10-fold the turbine rotor diameter³⁸. Only certain areas of the impact would be exposed to shadow flicker *for a significant amount of time*. The NEWEEP Webinar³⁹ gives a detailed discussion of the methodologies involved in forecasting time, place and extent of shadow flicker; the potential impact on residences in proximity to the shadow flicker; and proposed mitigation and management practices.

BQ3. WHAT IS THE LEVEL OF FLICKER EXPOSURE FROM A WIND TURBINE AND HOW DOES IT VARY BY DISTANCE AND CHARACTERISTICS OF THE TERRAIN SEPARATING THE WIND TURBINE FROM POTENTIALLY EXPOSED PEOPLE?

The timing, intensity and location of shadow flicker are influenced by turbine size and shape, landscape features, latitude, weather and wind farm layout. Reviews by Harding, Harding and Wilkins (2008), Verkuijlen et al. (1984) and Rideout, Copes and Bos (2010) provide guidance on the design of wind farms in order to reduce the risk of flicker-induced seizure, as summarised below:

- Shadow flicker wind turbines should only be installed if flicker frequency is maintained below 2.5 Hz, under all conditions. Turbine blades should be programmed to stop when blade rotation

³⁸ Thus the risk zone for a 90-m rotor diameter would be equivalent to a 900-m impact area.

³⁹ <http://www.windpoweringamerica.gov/filter_detail.asp?itemid=2967>

exceeds 3 Hz (60 rpm for a three-blade turbine). Most industrial turbines operate between 30 and 60 rpm.

- 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 reflection from turbine blades should be minimised.
- Wind farms should be placed at a distance sufficient to reduce contrast; that is the degree of sunlight occlusion by turbine blades. According to Harding, Harding and Wilkins (2008), 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 that is 1 m in diameter, this distance is 1.14 km (Harding, Harding & Wilkins 2008).
- The resulting flicker frequency, from a combination of blades when several turbines are aligned with the sun's shadow, could be higher than that from a single turbine. If the blades of a turbine are reflective, there is the possibility of flicker from reflected light at viewing positions that are unaffected by shadows.

Frequency thresholds and seizure risk from shadow flicker or blade glint

The Institute of Electrical and Electronics Engineers suggest that the health effects of flicker can be categorised into those that are immediate (effects resulting from a few seconds' exposure, such as epileptic seizures) and those that take time to develop (effects resulting from long-term exposure such as malaise, headaches and impaired visual performance). Epileptic seizures are associated with visible flicker, typically within the range 3–70 Hz, while human biologic effects due to invisible flicker (that which is not consciously perceivable by a human viewer) occur at frequencies above those at which flicker is visible but at <165 Hz (Wilkins, Veitch & Lehman 2010). Seizures induced by visual or photic stimuli are usually observed in individuals with certain types of epilepsy, particularly generalised epilepsy (Guerrini & Genton 2004). Approximately 3% of people with epilepsy are photosensitive (Rideout, Copes and Bos 2010).

In normal human physiology, millions of tiny electrical charges are relayed from nerve cells in the brain to all parts of the body. However, in patients with epilepsy there is a sudden and unusual interruption of this conduction process by intense bursts of electrical energy. This can temporarily affect a person's consciousness, bodily movements and sensation (NINDS 2012). Approximately 1 in 4000 individuals has photosensitive epilepsy. It is typically five times more common around puberty (age range 7–20 years) than in the general population. Photosensitive epilepsy can be induced by 'repetitive flashing lights' and 'static repetitive geometric patterns', with the flicker inducing transient abnormal synchronised activity of brain cells, affecting consciousness, bodily movements or sensation. However, the likelihood of a seizure depends on the location of stimulation within the visual field. Stimulation of central vision poses a higher risk of a seizure compared with stimulation of the visual periphery, although the latter may be more distinctive (Wilkins, Veitch & Lehman 2010).

The Wisconsin Wind Siting Council notes that there is some evidence that the interruption of sunlight by helicopter blades has caused seizures, and that there have been two unconfirmed reports of seizures due to shadow flicker (McFadden 2010).

Aspects of flicker that pose a seizure risk include:

- flash frequency in a frequency range 3–70 Hz (Harding, Harding & Wilkins 2008; Verkuijlen & Westra 1984; Wilkins, Veitch & Lehman 2010), with the greatest likelihood of seizures occurring at the frequency range 15–20 Hz
- brightness—stimulation in the scotopic or low mesopic range (<1 candela or cd/m^2) has a low risk, while there is a monotonic increase in risk with log luminance in the high mesopic and photopic range
- contrast with background lighting, such as the sun—contrasts above 10% are considered a potential risk (Harding, Harding & Wilkins 2008).

The risk of seizures from wind turbines in individuals with a risk of photosensitive epilepsy can be determined by modelling the light–dark contrasts of turbine shadows for worst case conditions, that is, a completely cloud-free atmosphere, with blade rotation in the vertical plane and on a line between the observer and the sun, directly facing the observer (Smedley, Webb & Wilkins 2009). The authors conclude that there is no evidence of epileptogenic risk to observers looking towards the horizon except when standing closer than 1.2 times the total turbine height on land (or closer than 2.8 times the total turbine height for marine environments). In addition, given the tendency of photosensitive individuals is to stare away from the sun (except when in a shadow zone), for an observer viewing the ground, the contrast is almost always insufficient to be epileptogenic. Finally, the authors suggest that large turbines are unlikely to rotate fast enough to induce seizures (<3 Hz, the lower frequency threshold at which seizures are a potential risk). The rotation frequency increases inversely with the blade length; thus, smaller micro-generation turbines are more likely to induce seizures if the intensity and stimulus conditions are met.

The Environment Protection and Heritage Council of Australia (EPHC; 2010) notes that the risk of seizures from modern wind turbines is negligible, given that less than 0.5% of the population are subject to epilepsy at any point in time and, of this proportion, 5% are vulnerable to strobe lighting (light flashes). In the majority of circumstances ($>95\%$ of the time), the frequency threshold for individuals susceptible to strobe lighting is >8 Hz, with the remainder affected by frequencies >2.5 Hz. The EPHC estimates that the probability of conventional horizontal-axis wind turbines causing an epileptic seizure for an individual experiencing shadow flicker is <1 in 10 million in the general population. They further indicate that blades from modern wind turbines are now treated with low-reflective coating that prevents glint from the blade surface, and thus the risk of blade glint is considered very low.

Harding, Harding and Wilkins (2008) and Verkuijlen et al. (1984) report that the shadow flicker frequencies of modern conventional horizontal-axis wind turbines are ≤ 1 Hz. Ellenbogen et al. (2012) support this view, indicating that shadow flicker emitted from wind turbines is usually in the range 0.3–1.0 Hz, which is well below the frequencies associated with seizure risk. The authors also note that frequency of shadow flicker emitted from wind turbines is proportional to the

rotational speed of the rotor multiplied by the number of blades; for large wind turbines these are typically in the range 0.5–1.1 Hz. Harding, Harding and Wilkins (2008) report that the cumulative risk of inducing a seizure at ≤ 3 Hz is approximately 1.7 per 100,000 *in a photosensitive population* (1.7 per 400 million persons in general).

McFadden et al. (2010) propose that shadow flicker is primarily an issue of annoyance at typical wind turbine frequencies (0.6–1.0 Hz). This is supported by Rideout, Copes and Bos (2010), who note that there is evidence that annoyance was more closely associated with whether shadow flicker occurred when people were at home, rather than with the duration of the exposure.

Systematic literature review

SQ4. IS THERE ANY RELIABLE EVIDENCE OF AN ASSOCIATION BETWEEN SHADOW FLICKER (PHOTOSENSITIVITY GREATER THAN 3 HZ) FROM WIND TURBINES AND ADVERSE HEALTH EFFECTS?

No studies reported on the health effects of shadow flicker from wind turbines. One Australian cross-sectional study with poor reporting provided information on the rates of annoyance from flickering in homes within 5 km and 10 km from Waterloo wind farm (Morris 2012). A summary of the study characteristics is in Table 31.

Table 31 Profile of one study assessing shadow flicker

Study	Design/ Sample	Exposure	Outcome measure	Other factors that may influence results
Morris (2012) Mt Lofty Ranges, Australia	Cross- sectional anonymous self- reporting survey. n=93 households Non- standardised survey developed by the authors. Intent of survey not masked from participants.	Households within 10 km of Waterloo Wind Farm, North Mount Lofty Ranges, South Australia. Subgroups within 0–5 km and 5–10 km.	Anyone in the household annoyed by flickering	<u>Confounders</u> Unclear as very little information was reported on participant or household characteristics or pre-existing health conditions. <u>Bias</u> Sample selection bias cannot be excluded as the response rate was only 40% of households surveyed (0– 10 km; 55% for 0–5 km). No masking of study intent may have resulted in recall bias. Differential participation rates by distance (selection bias). <u>Chance</u> No formal statistical tests of association were conducted.

Sufficient information was provided in the paper to calculate the odds of annoyance in respondents living within 5 km, and those living between 5 and 10 km, from the nearest wind turbine. Those living within 5 km of a wind turbine had over five times the odds of being annoyed by shadow flickering in their home than those who lived between 5 and 10 km away. Respondents claimed that flicker was annoying, distracting, and caused headaches and blurred vision (Table 32).

No adjustments were (or could have been) made to the results for differences between distance categories for age, gender, financial benefit from wind turbines, attitudes towards wind turbines in general or attitudes towards the visual impact of wind turbines on the landscape. It is therefore unknown whether any of these possibly confounding factors could have influenced the results. Selection bias could easily have affected the results since only 55% of those living within 5 km, and 34% of those living between 5 and 10 km responded to the survey and study intent was not masked.

Table 32 Association between distance from wind turbine and annoyance at shadow flicker

Study	Outcome measure	Distance from nearest industrial wind turbine		OR (95%CI)
		0–5 km (n=41)	5–10 km (n=52)	
Morris (2012) Australia	Annoyance at flicker in home	7/41 (17.1%)	2/52 (3.8%)	5.14 (1.01, 26.29)

Bolded values indicate statistically significant differences.

Abbreviations: OR = odds ratio; CI = confidence interval

SUMMARY: DIRECT EVIDENCE ON SHADOW FLICKER

SQ4. Is there any reliable evidence of an association between shadow flicker from wind turbines and adverse health effects?

One small Australian study found that shadow flicker was more likely to annoy a household member with increasing proximity of a household to a wind farm. Bias and confounding cannot be excluded as possible explanations for this finding.

An assessment of the body evidence addressing this question is given in Box 4.

Box 4 Evidence statement matrix for shadow flicker

Key question: Is there any reliable evidence of an association between shadow flicker from wind turbines and adverse health effects? If so: A. How strong is this association? B. How does the strength of this association relate to <i>distance</i> from wind turbines? <i>[Systematic Review question on distance has been merged here]</i> C. Might this association be explained by: i. chance? ii. bias? or iii. confounding?		Morris (2012)
1. Evidence-base (Number of studies, level of evidence, and risk of bias and confounding in the included studies)		
1 level IV study (cross-sectional study) at high risk of bias and confounding	A	One or more level I studies with a low risk of bias or several level II studies with a low risk of bias and confounding
	B	One or two level II studies with a low risk of bias or SR/several level III studies with a low risk of bias and confounding
	C	One or two level III studies with a low risk of bias or level I or II studies with a moderate risk of bias and confounding
	D	Level IV studies or level I to III studies/SRs with a high risk of bias and confounding
2. Consistency (If only one study was available, rank this component as 'not applicable')		
Only one study	A	All studies consistent
	B	Most studies consistent and inconsistency can be explained
	C	Some inconsistency, reflecting genuine uncertainty around question
	D	Evidence is inconsistent
	NA	Not applicable (one study only)
3. Population health impact (Indicate in the blank space below if the study results varied according to some unknown factor (not simply study quality or sample size) and thus the population health impact of the exposure could not be determined; or whether the impact could not be determined because the studies were underpowered and could not be meta-analysed. Otherwise, provide justification for your selection of the A–D rating, i.e. the size of the effect and precision of the estimate of adverse health effects)		
One small Australian study reported found that shadow flicker was more likely to annoy a household member with increasing proximity of a household to a wind farm (17.1% at 0-5km and 3.8% at 5-10km). While bias and confounding could explain this finding, if true, shadow	A	Very large
	B	Substantial

flicker would have a moderate impact on annoyance in the exposed population. Annoyance, though, is not a health effect	C	Moderate— for other relevant non-health effect (annoyance)
	D	Unknown—for health effects
4. Generalisability <i>(How well does the body of evidence match the population being targeted by the NHMRC advice?)</i>		
The generalisability of the study is limited, given the poor response rates. No sample characteristics provided.	A	Evidence directly generalisable to target population
	B	Evidence directly generalisable to target population with some caveats
	C	Evidence not directly generalisable to the target population but could be sensibly applied
	D	Evidence not directly generalisable to target population and hard to judge whether it is sensible to apply
5. Applicability <i>(Is the body of evidence relevant to the Australian setting for the exposure?)</i>		
The study was based in Australia.	A	Evidence directly applicable to Australian exposure setting
	B	Evidence applicable to Australian healthcare exposure setting with few caveats
	C	Evidence probably applicable to Australian exposure setting with some caveats
	D	Evidence not applicable to Australian exposure setting
Other factors <i>(Indicate here any other factors that you took into account when assessing the evidence-base (e.g. issues that might cause the group to downgrade or upgrade the recommendation, such as the biological plausibility evidence presented in Background Question 4)</i>		
The information addressing Background Questions 3 and 4 (see relevant sections of the report) was not sufficiently persuasive to result in an upgrade of the evidence rating obtained from the direct evidence. A mechanism of action for shadow flicker to cause adverse health effects was identified (in individuals with photosensitive epilepsy—a very rare condition in the general population) but it was unclear whether the shadow flicker produced by wind turbines would produce seizures. The shadow flicker investigated in laboratory circumstances was of a different type than that produced by wind turbines. The quality of the evidence-base and lack of any evidence relating to direct health effects was given greatest weight when formulating the overall rating.		
EVIDENCE STATEMENT MATRIX		
<i>Please summarise the synthesis of the evidence relating to the key question, taking all the above factors into account.</i>		
Component	Rating	Description
1. Evidence-base	D	One cross-sectional study with high risk of bias
2. Consistency	NA	NA (one study only)

3. Population health impact	D / C	Unknown—for health effects Moderate— for other relevant non-health effect (annoyance)
4. Generalisability	C	Evidence not directly generalisable to the target population but could be sensibly applied
5. Applicability	A	Evidence directly applicable to Australian exposure setting
<i>Evidence statement</i> No studies reliably assessed whether shadow flicker is associated with health outcomes. One small Australian study of at high risk of bias and confounding reported that shadow flicker was more likely to annoy a household member with increasing proximity of households to a wind farm.		<i>Evidence rating</i> D

Parallel evidence

BQ4. IS THERE BASIC BIOLOGICAL EVIDENCE, OR EVIDENCE FROM RESEARCH INTO OTHER CIRCUMSTANCES OF HUMAN EXPOSURE TO FLICKER, THAT MAKE IT PLAUSIBLE THAT WIND TURBINES CAUSE ADVERSE HEALTH EFFECTS?

The parallel evidence identified for Background Question 4 concerning the effects of shadow flicker on human health is summarised in Table 33. This evidence was used to address the biological plausibility that wind farms could cause adverse health effects. The specific limitations of each of the studies are also provided.

One small RCT (Pohl, Faul & Mausfeld 1999) and a small prospective cohort study (Shirakawa et al. 2001) recruited subjects to participate in experimental conditions simulating flicker. Pohl and colleagues considered a range of stress-related outcomes but found no differences between the exposed group (60 minutes of simulated shadow flicker) and the control group (conditions under the same lighting but without flicker). The applicability of this study in the context of wind farms is uncertain as the frequencies used in the flicker experiments were not stated. Shirakawa et al. reported on photoparoxysmal response to a range of frequencies relevant to flicker from wind turbines (>3 Hz). However, flicker exposure was via a television medium (coloured light) and *only photosensitive individuals* were included as participants. Therefore, its results are of uncertain relevance to shadow flicker associated with wind turbines.

Table 33 Parallel evidence examining the association between shadow flicker and adverse health effects

Study	Design	Exposure	Outcomes	Limitations
Pohl, Faul and Mausfeld (1999) German government-sponsored study	RCT 2 groups of males and females: Group 1, 32 students (mean age = 23 years); Group 2, 25 professionals (mean age = 47 years) Each group randomly assigned to either 60 minutes of simulated flicker (experimental group) or similar lighting conditions without periodic shadow or flicker. Study consisted of 6 test and measurement phases: 2 before the light was turned on; 3 at intervals of 20 minutes while simulated flicker or the control condition was in progress; 1 after simulated flicker was turned off.	60 minutes of simulated flicker.	Stress-related health effects: general performance stress indicators (arithmetic, visual search tasks); mental and physical wellbeing; cognitive processing; and stress in the autonomic nervous system (heart rate, blood pressure, skin conductance and finger temperature).	There were inadequate data presented in the review by Ellenbogen et al. (2012), which included this study. Pohl, Faul and Mausfeld (1999) were published in German and were not translated because an inclusion criterion for BQ4 was English literature only.
Results Only a short narrative summary of results was included in the review by Ellenbogen et al. (2012). The original article by Pohl, Faul and Mausfeld (1999) was in				

Study	Design	Exposure	Outcomes	Limitations															
German. Summary Systemic effects were comparable across groups. On the results of this study, Ellenbogen et al. (2012) note that ‘there is limited evidence primarily from a study by Pohl, Faul and Mausfeld (1999) that prolonged shadow flicker (more than 30 minutes) can result in transient stress-related effects on cognition (concentration, attention) and autonomic nervous system functioning (heart rate, blood pressure)’.																			
Shirakawa et al. (2001)	Non-randomised provocation study comparing multiple groups with varying levels of colour flicker at varying frequencies. All subjects were photosensitive (n=35).	Rates of photoparoxysmal response (PPR) provocation.		The study examined photosensitive individuals—20/35 (57%) were being treated with antiepileptic drugs. It is not known what proportions of residents living near wind turbines are photosensitive. The exposures were colour related to mimic flicker emitted from a television. It is difficult to apply these results to the wind turbine flicker setting. Potential for observer bias given the lack of concealment of allocation.															
Results <i>Proportions of individuals experiencing PPR provocation at 3, 10, 20 and 30 Hz among the 35 subjects</i> <table> <tr> <td></td><th colspan="4">Frequency</th></tr> <tr> <td></td><th>3 Hz</th><th>10 Hz</th><th>20 Hz</th><th>30 Hz</th></tr> <tr> <td>Subjects with PPR provocation, %</td><td>5.7</td><td>28.6</td><td>22.9</td><td>28.6</td></tr> </table> Summary The PPR provocation rates at 10, 20, and 30 Hz were significantly greater than at 3 Hz ($p < 0.01$ for all comparisons).						Frequency					3 Hz	10 Hz	20 Hz	30 Hz	Subjects with PPR provocation, %	5.7	28.6	22.9	28.6
	Frequency																		
	3 Hz	10 Hz	20 Hz	30 Hz															
Subjects with PPR provocation, %	5.7	28.6	22.9	28.6															

Abbreviations: RCT = randomised controlled trial; PPR = photoparoxysmal response; Hz = hertz

SUMMARY: MECHANISTIC AND PARALLEL EVIDENCE ON SHADOW FLICKER

BQ2. By what specific physical emissions might wind turbines cause adverse health effects? (Shadow Flicker)

Shadow flicker occurs as turbine blades pass before the sun and create shadows. Exposure to flicker from a turbine is determined by the hub height, blade diameter, height of the sun and blade direction relative to the observer, and these variables are affected by the time of day, time of year, wind direction and geographical location (Harding, Harding & Wilkins 2008; Verkuijlen & Westra 1984).

It is well recognised that shadow flicker exposure can affect health by inducing seizures in those prone to photosensitive epilepsy. This very rare condition can be induced by repetitive flashing lights and static repetitive geometric patterns, with the flicker inducing transient abnormal synchronised activity of brain cells and affecting consciousness, bodily movements and/or sensation.

BQ3. For each such emission, what is the level of exposure from a wind turbine and how does it vary by distance and characteristics of the terrain separating a wind turbine from potentially exposed people?

The timing, intensity and location of shadow flicker are influenced by turbine size and shape, landscape features, latitude, weather and wind farm layout. 'Safe distances to reduce shadow flicker' would depend on the specific nature of the project and the presence of residences or roadways and geographic layout. Forestry and existing shadows would diminish the nuisance from turbine-produced shadow flicker, whereas open-land areas (such as farmland) are more susceptible to flicker-induced annoyance. Generally, a shadow flicker 'risk zone' would incorporate an impact area that is 10-fold the turbine rotor diameter. Only certain areas of the impact would be exposed to shadow flicker for a significant amount of time. The frequency of shadow flicker emitted from wind turbines is proportional to the rotational speed of the rotor multiplied by the number of blades; for large wind turbines these are typically in the range 0.5–1.1 Hz.

The Environment Protection and Heritage Council of Australia (EPHC; 2010) note that the risk of seizures from modern wind turbines is negligible, given that less than 0.5% of the population are subject to epilepsy at any point in time and, of this proportion, 5% are vulnerable to strobe lighting (light flashes). In the majority of circumstances (>95% of the time), the frequency threshold for individuals susceptible to strobe lighting is >8 Hz, with the remainder affected by frequencies >2.5 Hz. Wind turbine flicker is usually below 1 Hz. The EPHC estimates that the probability of conventional horizontal-axis wind turbines causing an epileptic seizure for an individual experiencing shadow flicker is <1 in 10 million in the general population.

SUMMARY (CONT.)

BQ4. Is there basic biological evidence, or evidence from research into other circumstances of human exposure to physical emissions that wind turbines produce, that make it plausible that wind turbines cause adverse health effects?

Epileptic seizures are associated with visible flicker, typically within the range 3–70 Hz, while human biologic effects due to invisible flicker (that which is not consciously perceivable by a human viewer) occur at frequencies above those at which flicker is visible but at <165 Hz (Wilkins, Veitch & Lehman 2010).

The sparse laboratory evidence available investigating the association between shadow flicker and health outcomes was of uncertain applicability to the shadow flicker conditions produced by wind turbines. One study found no difference in stress-related outcomes between groups exposed and not exposed to shadow flicker but it could not be determined whether the flicker frequencies investigated were similar to those produced by wind turbines (Pohl, Faul & Mausfeld 1999). The other study found photoparoxysmal responses to a range of frequencies relevant to the flicker produced by wind turbines (>3 Hz) but the flicker exposure involved coloured light, rather than shadow, and all of the participants were photosensitive individuals (Shirakawa et al. 2001).

ELECTROMAGNETIC RADIATION

BQ2. BY WHAT SPECIFIC PHYSICAL EMISSIONS MIGHT WIND TURBINES CAUSE ADVERSE HEALTH EFFECTS?

Electromagnetic radiation (EMR; X-rays, ultraviolet rays, visible light, infrared rays and radio waves) consists of electric and magnetic energy that is transmitted in a wavelike pattern. Magnetic fields (MF) occur where any electric conductor has an electrical current flowing through it. Humans are continuously exposed to time-varying low-frequency EMFs from natural sources (solar activity, earth and human body magnetic fields) (Ahlbom et al. 2001), radio and TV transmission devices, electrical power lines and wiring, and electrical appliances (Ahlbom et al. 2001; EPHC 2010; Rideout, Copes and Bos et al. 2010). Three types of EMF commonly present in the environment are (WHO 2012c):

- extremely low-frequency electromagnetic fields (ELFs) (range <300 Hz)
- intermediate frequency fields (range 300 Hz to 10 MHz)
- radiofrequency fields (range 10 MHz to 300 GHz).

Electrical currents are a vital part of normal bodily function. Biochemical mechanisms and nerve transmission utilise electric impulses. The impact of external exposure to EMF on the human body and its cells depends mainly on the EMF frequency and magnitude or strength (WHO 2002). The frequency (Hz) is the number of oscillations or cycles per second.

Concerns regarding the safety of EMF increased with the publication of an early study in which an association was observed between the risk of childhood leukaemia and the degree of EMF radiation exposure from electricity transmission lines (Wertheimer & Leeper 1979). Further research has been conducted on adults regarding possible occupational EMF associations with cancer, cardiovascular, neurological, psychological and reproductive conditions.

ELF refers to the electromagnetic radiation produced by the flow of electrical current. Examples of sources are electrical distribution cables and electrical equipment, including household appliances. ELFs are also produced by wind turbines, specifically by the grid connection lines, turbine generators, electrical transformers and underground collector network cabling. Rideout, Copes and Bos (2010) note that grid connection lines generate ELF levels that are comparable to those emitted from household appliances. For this reason, ELF is the focus of this review and no further consideration is given to EMF in the intermediate and radiofrequency ranges.

ELF can penetrate the human body and induce electrical currents inside the body. Radio frequency EMF penetrates only a short depth into the tissue and does not induce currents. The induced current strength or magnitude is influenced by the intensity of the outside magnetic field and the size of the loop through which the current flows. Sufficiently large currents can cause stimulation of nerves and muscles (HPA 2012; ICNIRP 2012; NIEHS 2012; WHO 2012a).

BQ3. WHAT IS THE LEVEL OF EMR EXPOSURE FROM A WIND TURBINE, AND HOW DOES IT VARY BY DISTANCE AND CHARACTERISTICS OF THE TERRAIN SEPARATING A WIND TURBINE FROM POTENTIALLY EXPOSED PEOPLE?

Levels of EMF emitted from wind turbines

For wind farms, EMF is emitted from grid connection lines, underground collector network cabling, electrical transformers and turbine generators. Rideout, Copes and Bos (2010) note that grid connection lines generate low levels of EMF that are comparable to those emitted from household appliances. Underground cables effectively generate no EMF at the surface because of positioning of phase conductors and screening of cables, whereas transformers generate the highest EMF levels. The authors also noted that turbine generators are around 60–100 m above ground level and so there is little or negligible EMF at ground level.

Magnetic field measurements, conducted by Windrush Energy from Windrush wind turbines, were 0.4 mG (milligauss⁴⁰) or 0.04 μ T (microtesla) in front of a turbine door, with typical values in the vicinity of wind turbines of 0.004 μ T (Windrush Energy 2004). The acceptable EMF health threshold is 83.3 μ T (Ahlbom et al. 2001). Windrush indicate that the EMF level emitted from a 2-MW wind turbine set back at 550 m is approximately 12 times less than the EMF exposure of a driver and front seat passenger sitting approximately 1.5 m from the average car alternator. The exposure is also analogous to a hand-held household hair dryer (Windrush Energy 2004).

Table 34 summarises typical magnetic field strengths for different household appliances at various distances. The magnetic field strength of the majority of household appliances at a distance of 30 cm is well below the guideline limit for the general public of 100 μ T (WHO 2012b). A World Health Organization report on EMF and health concluded that magnetic field strength rapidly decreases as distance from the appliance increases. For the majority of household appliances that are not operated very close to the body (at a distance of 30 cm), the surrounding magnetic fields are 100 times *lower* than the guideline limit of 100 μ T at 50 Hz (83 μ T at 60 Hz) for the general public. Thus, if human exposure to EMF from wind turbines is considered to be of similar strength to that emitted by household appliances, these conclusions would have similar applicability.

⁴⁰ Milligauss and microtesla (μ T) are units for magnetic field strength in common usage; 10 mG = 1 μ T.

Table 34 Typical magnetic field strength of household appliances at various distances

Electric appliance	3 cm distance (μT)	30 cm distance (μT)	1 m distance (μT)
Hair dryer	6–2000	0.01–7	0.01–0.03
Electric shaver	15–1500	0.08–9	0.01–0.03
Vacuum cleaner	200–800	2–20	0.13–2.00
Fluorescent light	40–400	0.5–2.0	0.02–0.25
Microwave oven	73–200	4–8	0.25–0.60
Portable radio	16–56	1	<0.01
Electric oven	1–50	0.15–0.5	0.01–0.04
Washing machine	0.8–50	0.15–3.00	0.01–0.15
Iron	8–30	0.12–0.30	0.01–0.03
Dishwasher	3.5–20	0.6–3.0	0.07–0.3
Computer	0.5–30	<0.01	NA
Refrigerator	0.5–1.7	0.01–0.25	<0.01
Colour TV	2.5–50	0.04–2.00	0.01–0.15

Normal operating distance is given in bold.

Abbreviations: T = tesla; NA = not applicable. All appliances operate at a frequency of 50 Hz; 1 μT = 10 mG

Source: WHO (2012a)

Systematic literature review

SQ5. IS THERE ANY RELIABLE EVIDENCE OF AN ASSOCIATION BETWEEN ELECTROMAGNETIC RADIATION FROM WIND TURBINES AND ADVERSE HEALTH EFFECTS?

No studies were identified that considered the effect of ‘electromagnetic radiation’, as it relates to wind turbines, on human health. Given the lack of evidence to answer this question, an Evidence Statement Form was not completed and an evidence statement or conclusion was not able to be made.

Parallel evidence

BQ4. IS THERE BASIC BIOLOGICAL EVIDENCE, OR EVIDENCE FROM RESEARCH INTO OTHER CIRCUMSTANCES OF HUMAN EXPOSURE TO ELECTROMAGNETIC RADIATION, THAT MAKE IT PLAUSIBLE THAT WIND TURBINES CAUSE ADVERSE HEALTH EFFECTS?

The parallel evidence identified for Background Question 4 concerning the effects of EMR in the ELF frequency range on human health is summarised in Table 38. This evidence was used to address the biological plausibility that wind farms could cause adverse health effects if they produced significant ELF. The specific limitations of each of the studies are also provided.

Three studies by Johansen and colleagues considered the potential health effects of EMR. Reported outcomes were diseases of the central nervous system (CNS), a range of cancers and the incidence of cardiac pacemaker implantation (Johansen 2000; Johansen, Feychting et al. 2002; Johansen & Olsen 1998). Slight increases for some diseases of the CNS (senile dementia, motor neuron diseases, amyotrophic lateral sclerosis (ALS)) were reported among exposed groups. However, the retrospective study design is likely to have resulted in exposure misclassification, while the exposed and non-exposed groups may have differed with respect to demographic factors and health and disease status. It is therefore uncertain whether the differences in CNS disease risk were due to ELF or to bias or confounding. A review by Ahlbom et al. (2001) considered the effects of environmental ELF on various cancers and ALS, noting an increase in the risk of childhood leukaemia and ALS for the exposed group, but the authors cautioned that the results are highly likely to have been affected by bias and confounding. One study reported a statistically significant effect of ELF on sleep (Åkerstedt et al. 1999), although the absolute impact was not considered meaningful.

According to the WHO (2012), the acceptable ELF health threshold is 100 μT (1000 mG). However, epidemiological studies of magnetic fields have consistently found an association between ELF at exposures of 0.4 μT or above and childhood leukaemia (Ahlbom et al. 2001), although lack of a known mechanism and negative animal data prevent a conclusion that the ELF and childhood leukaemia association is causal (Kheifets & Shimkhada 2005). Other authors make the more specific claim that prolonged exposure to power frequency ELF at levels above what is normally encountered (>4 mG or >0.4 μT) may be associated with an increased risk of childhood leukaemia (Karipidis & Martin 2005)⁴¹. These authors conducted a pilot study to characterise power-frequency ELF strength in private residences in metropolitan Melbourne, Victoria, Australia. The main objective was to gather results on the distribution of average ELF in homes and the proportion of homes with averages above 0.4 μT . The rationale was that this investigation provided data to inform a precautionary approach to EMF. The authors explained that such an

⁴¹ The definition of 'levels above what is normally encountered' could not be clarified as the figure of >4 mG was based on a publication (ICNIRP 2003) not available to the authors at the time of undertaking this review. The quoted figure has been accepted as valid and 'levels normally encountered' has been interpreted to mean levels of EMF that people would commonly encounter during the course of their daily lives. For the same reason it could not be determined what is meant by 'prolonged exposure'.

approach necessitates ‘knowledge of the exposure potentially related to the possible risk’, meaning that ‘one should know what proportion of the population, and in particular children, are exposed to time-averaged levels above 4 mG’ (0.4 μ T).

Table 35 shows magnetic field spot measurements and the percentage of homes for which each level was greater than 0.4 μ T (95% CI). The results for the spot measurements did not, on average, exceed 0.4 μ T despite isolated measurements above this figure. The authors acknowledge that the relevance of these findings is uncertain, the measurement not being representative of the population due to the small sample (Karipidis & Martin 2005).

Table 35 Magnetic field spot measurements at selected locations in 26 homes and percentage of homes (95%CI) for which the level exceeded 0.4 μ T^a at that location

Location	No. of homes	Mean, μ T	Median, μ T	SD, μ T	Min, μ T	Max, μ T	% homes >0.4 μ T [95%CI]
Front gate	25	0.334	0.200	0.319	0.02	1.16	28 [14, 48]
Front yard	23	0.183	0.140	0.161	0.02	0.69	9 [1, 28]
Front door	26	0.158	0.095	0.218	0.02	1.12	8 [1, 26]
Living room	26	0.122	0.080	0.150	0.01	0.58	8 [1, 26]
Kitchen	26	0.107	0.060	0.123	0.01	0.50	4 [0.1, 21]
Master bedroom	26	0.139	0.075	0.194	0.01	0.92	12 [3, 30]
Child's bedroom	26	0.151	0.080	0.212	0.01	0.99	12 [3, 30]
Study		0.147	0.070	0.197	0.01	0.59	14 [3, 42]
Backyard		0.097	0.050	0.140	0.01	0.68	4 [0.1, 21]

Abbreviations: μ T = microtesla; SD = standard deviation; CI = confidence interval

^a All results have been converted from milligauss to microtesla.

Source: Karipidis and Martin (2005)

Magnetic fields from appliances usually showed considerable variation from house to house for the same types of appliance. Fields produced by microwave ovens were observed to have the highest levels. Table 36 shows descriptive statistics for selected appliances.

Table 36 Descriptive statistics for magnetic fields from selected appliances measured at a nominal 30-cm separation^a

Appliance	No. of homes	Mean, μT	Median, μT	SD, μT	Min, μT	Max, μT
Television	26	1.01	0.99	0.57	0.14	2.54
Microwave oven	22	9.71	10.60	5.45	0.77	18.80
Kettle	22	0.53	0.47	0.32	0.17	1.38
Clock radio	22	0.48	0.45	0.25	0.14	0.96
Hair dryer	9	2.53	0.95	3.18	0.26	9.90
Computer	17	0.23	0.23	0.12	0.06	0.52

Abbreviations: μT = microtesla; SD = standard deviation

^a All results have been converted from milligauss to microtesla.

Source: Karipidis and Martin (2005)

These results suggest that the magnetic fields associated with common household appliances do not reach average levels exceeding 0.4 μT , and that the levels of ELF experienced by individuals on a day-to-day basis around the home may occasionally fall within ranges consistent with an elevated risk of childhood leukaemia where the exposure is close and prolonged⁴² (ICNIRP 2003). However, it is uncertain how many of, or for how long, these sources would regularly be within 30 cm (the nominal separation) of residents for extended periods.

A WHO report on EMF and health concluded that magnetic field strength rapidly decreases as distance from the appliance increases (WHO 2012b). The WHO noted that, for the majority of household appliances that are not operated in very close proximity to the body (i.e. >30 cm), the magnetic fields surrounding these appliances are substantially lower than the WHO guideline limit of 100 μT at 50 Hz (83 μT at 60 Hz) for the general public. Thus, if human exposure to ELF from wind turbines is considered to be of similar strength to that emitted by household appliances, these conclusions would have similar applicability. As noted above, there is some evidence to suggest that the levels of ELF measured around turbines are less than those measured close to household appliances and in a number of working and home environments. These measurements were taken at proximities from the turbines that would be much closer than that of residences near turbines (Windrush Energy 2004). However, the measurements were only summarised (no datasets) and were taken by a party within the wind power industry. Comprehensive measurements and data reporting across a range of wind farms have not been provided by an independent investigator.

⁴² As the International Committee Report could not be accessed, the definition of prolonged is unknown; however, one example of prolonged exposure within close range was given by Karipidis and Martin (2005)—a clock radio on a bedside table.

Another pilot study (Kim & Cho 2001) conducted in Korea compared personal exposure to ELF among ‘occupational’ and ‘non-occupational’ groups⁴³ in different indoor environments (at work, transportation and at home) and outdoors. The results of magnetic field strength measurements taken in the various environments for these groups are shown in Table 37.

Table 37 Average levels of personal exposure (μT) to magnetic fields in occupational and non-occupational groups

	Occupational group (O)				Non-occupational group (NO)		Ratio
	Electrician (n=11)	Medical computer operator (n=6)	Subway driver (n=9)	Transformer worker (n=11)	Graduate student (n=34)	Office worker (n=31)	O/NO
Indoor, μT :							
at work	0.64	0.46	0.35	1.21	0.09	0.09	7.44
in transport	0.42	0.18	0.26	0.22	0.22	0.13	1.50
at home	0.18	0.18	0.08	0.08	0.07	0.07	1.86
etc. ^a	0.13	0.11	0.18	0.33	0.13	0.06	1.90
Outdoor, μT	0.26	0.08	0.15	0.11	0.17	0.09	1.15
Total, μT	0.41	0.27	0.18	0.83	0.08	0.08	5.25

Abbreviations: μT = microtesla; O/NO = occupational/non-occupational

^a It is unclear from the publication which indoor environments provided the measurements shown in this row.

Source: Kim and Cho (2001)

The study groups without probable occupational exposure to ELF had average workplace levels of exposure that were similar to the home levels—0.09 μT compared with 0.07 μT . In contrast, those with occupational exposure had much higher levels of workplace exposure (0.35–1.21 μT) than home exposure (0.08–0.18 μT).

The former findings are generally consistent with those of an investigation that measured ELF exposure in 10 women working at a television studio in Toowong, Queensland, Australia (Armstrong et al. 2007). The investigation was in response to a breast cancer cluster observed among the 10 women who were studied. The average levels measured at Toowong, with the exception of measurements for a staff member who worked in the radio building, were similar to those in the Korean study without probable occupational exposure. Levels measured from the radio building were appreciably less than that measured on any of the Korean groups with probable occupational exposure.

⁴³ While the publication by Kim and Cho (2001) did not provide explicit definitions for these groups, it is evident that ‘occupational’ was intended to encompass occupations hypothesised to be associated with higher levels of ELF exposure than ‘non-occupational’, which included graduate students and office workers.

Overall, the findings of the Toowong study suggest that ELF was a very unlikely cause for the observed breast cancer cluster, as the levels of exposure were very unlikely to have been materially different from levels common in residential buildings, and probably workplaces, in Australia.

Given that the only available estimates of ELF levels in proximity to wind farms (Windrush Energy 2004) are lower than the levels observed in this evidence, it would be reasonable to conclude that the likelihood of adverse health effects from ELF emitted by wind turbines is probably very low, albeit currently unknown.

Several of the ELF studies shown in Table 38 used a job-exposure matrix. This has the potential to result in misclassification between adjacent categories of exposure (Johansen et al. 2002). Three key limitations with respect to ELF exposure assessment discussed in the literature include the lack of knowledge about a relevant metric and the relevant exposure induction period; the retrospective nature of exposure assessment in the majority of the studies; and incomplete characterisation of exposure sources, and lack of consensus on combining exposures from different sources into one metric (Ahlbom et al. 2001).

The cyclical nature of exposures from power lines makes the nature of the exposure complex, multifaceted and highly variable (daily, seasonal and secular patterns; variation in residential exposure due to differences in power usage (intensity and duration) across both time and electrical appliances). There are also two additional key issues for consideration: 1) the magnetic field exposure from sources outside those examined in the studies, such as magnetic fields outside the home; and 2) residential mobility.

It is difficult to precisely determine if there exists an aetiological relationship between ELF exposure and chronic disease endpoints such as cancer in the absence of prospective attainment of accurate data. However, among the evaluated studies, the strongest evidence of an association was in relation to postnatal exposures to ELF above 0.4 μ T and childhood leukaemia, based on two separate non-systematic reviews presenting pooled analyses (Ahlbom et al. 2001; Kheifets & Shimkhada 2005).

While there are numerous studies of childhood leukaemia and ELF exposure, studies of ELF exposure and other diseases (particularly adult diseases) are much more limited. This is largely due to difficulties typically encountered in designing studies that adequately assess exposure (Kheifets & Shimkhada 2005). Outside the study of childhood leukaemia, results from the ELF studies are characterised by a high degree of heterogeneity and are inconclusive. The applicability of the results obtained in the included ELF studies to the wind farms context is uncertain due to scant data (one industry example only (Windrush Energy 2004)) on the magnitude and/or level (quantity) of ELF present in the vicinity of wind turbines.

Table 38 Parallel evidence examining the association between extremely low frequency electromagnetic fields (ELF) and adverse health effects

Study	Design	Exposure	Outcomes	Limitations
Åkerstedt et al. (1999)	Cross-over design comparing sleep with and without exposure to a 50 Hz/1 μ T electrical field. n=18 healthy subjects (age range 18–50 years).	After a night of habituation, subjects were exposed 3–5 days later to a night with a 1 μ T EMF field on or off. Magnetic fields measured using a 3-axis magnetometer. The authors note that the generated field did not cause any sound.	Effects on sleep (polysomnography). Effects on sleep-related hormones (melatonin, growth hormones, cortisol and prolactin).	Authors stated that, despite statistically significant differences, effects were far from ‘clinical significance’.
Results <i>Mean values for sleep variables with ELF ‘Off’ and ‘On’</i>				
	On, mean $\pm$ SE	Off, mean $\pm$ SE	p value	
Total sleep time	424 $\pm$ 9	407 $\pm$ 11	0.04	
Sleep efficiency	0.86 $\pm$ 0.02	0.82 $\pm$ 0.02	0.05	
Awakenings	1.34 $\pm$ 0.03	2.41 $\pm$ 0.04	0.07	
Sleep latency	18 $\pm$ 4	22 $\pm$ 6	0.29	
SWS latency	12 $\pm$ 1	14 $\pm$ 2	0.20	
REM sleep latency	81 $\pm$ 9	80 $\pm$ 9	0.44	
Stage 1 sleep	8 $\pm$ 2	10 $\pm$ 1	0.16	
Stage 2 sleep	219 $\pm$ 10	211 $\pm$ 10	0.10	
SWS	97 $\pm$ 4	82 $\pm$ 6	0.01	
SWA%	100	80 $\pm$ 9	0.02	

Study	Design	Exposure	Outcomes	Limitations				
REM	107±7	104±6	0.34					
Stage wake + movement	45±9	54±8	0.10					
Subject rated ^a								
Ease of falling asleep	4.1±0.2	4.2±0.2	0.15					
Ease of awakening	3.6±0.2	3.8±0.2	0.12					
Sleep quality	3.7±0.2	4.0±0.2	0.09					
Sleep depth	3.9±0.2	3.4±0.2	0.01					
Undisturbed sleep	3.2±0.2	3.3±0.2	0.20					
All values given in minutes except for sleep efficiency (proportion), SWA (%) and subjective ratings (point scale; see ^a below).								
^a The Karolinska Sleep Diary was used. Items were scored 1 to 5, where ‘5’ indicated highest quality or greatest ease.								
SWS, SWA, REM, see Abbreviations list at end of this table.								
<i>Mean and ANOVA results for plasma hormone levels at five time points with ELF ‘Off’ and ‘On’</i>								
	23.00	24.00	2.30	5.00	8.00	<i>F^{time}</i>	<i>F^{condition}</i>	<i>F^{tc}</i>
Melatonin, Off	34±8	53±8	110±11	60±11	28±7	NA	NA	NA
Melatonin, On	25±7	36±7	67±8	55±8	35±7	5.7 ^a	1.5	0.8 ^a
GH, Off	1.6±0.9	1.3±0.4	2.0±0.1	0.6±0.1	0.3±0.1	NA	NA	NA
GH, On	1.5±0.6	2.5±0.6	1.2±0.1	0.6±0.1	0.3±0.1	6.0 ^b	0.6	1.6 ^a
Cortisol, Off	105±15	102±24	70±20	184±20	357±20	NA	NA	NA
Cortisol, On	103±11	114±24	108±24	209±24	365±18	63.1 ^c	3.2	0.5 ^a
ACTH, Off	1.8±0.4	1.3±0.1	1.7±0.3	3.1±0.5	5.5±2.5	NA	NA	NA
ACTH, On	1.6±0.3	1.8±0.7	1.2±0.1	3.0±0.4	4.2±0.3	22.9 ^c	3.6	2.2 ^a
Prolactin, Off	5.6±0.5	5.9±1.1	9.6±1.2	9.0±0.9	12±1.5	NA	NA	NA
Prolactin, On	5.9±0.7	4.6±0.4	9.3±0.7	7.6±0.7	11±1.2	19.9 ^c	1.3	0.4 ^a

Study	Design	Exposure	Outcomes	Limitations
F^{time} = adjusted statistic derived from testing for changes across the night with 'time' as a factor; $F^{condition}$ = adjusted statistic derived from testing for changes across the night with 'condition' (off/on) as a factor; F^{tc} = adjusted statistic derived from testing for changes across the night with 'time' and 'condition' as factors. p values: ^a <0.05; ^b <0.01; ^c <0.001. Melatonin and ACTH (see Abbreviations list at end of this table) levels given in pmol/L, cortisol in nmol/L, GH (see Abbreviations) and prolactin in µg/L (see Glossary for definitions of these units). Summary ELF exposure was associated with reduced: total sleep time, sleep efficiency and slow wave activity (SWA). There were no differences in plasma hormone levels between exposed and non-exposed phases.				
Johansen (2000) [†]	Retrospective cohort study to examine whether there was any association between ELF and diseases of the CNS in approximately 31,000 subjects employed in Danish utility companies between 1900 and 1993. After classification of exposure, data were linked to the nationwide, population-based Danish national register of patients to determine the number of CNS disease cases.	A job-exposure matrix specific for ELF (that distinguished between 25 job titles held by workers in utility companies) was constructed and, for each of the 475 combinations of job title and work area, an average level of exposure of 50 Hz ELF during a working day was assigned. This was grouped into five categories of ELF exposure: background exposure (0.09 µT), low exposure (0.1–0.29 µT), medium exposure (0.3–0.99 µT), and high exposure (>1.0 µT).	Diseases of the CNS—dementia, demyelinating diseases, cerebral palsy, epilepsy, motor neuron diseases and spinal medullary disease.	Limitations include retrospective design of the study, potential for misclassification of exposure and non-randomised nature of the comparison.
Results				

Study	Design		Exposure			Outcomes		Limitations			
<i>Observed (O) and expected (E) discharges (1978–1993) due to CNS diseases among 30,631 workers with ≥3 months employment at a utility company in Denmark during 1900–1993</i>											
		Men					Women				
		O	E	O/E	95% CI			O	E	O/E	95% CI
Disease (ICD-8)											
Senile dementia		122	105.1	1.16	[0.16,1.39]			6	11.95	0.50	[0.18,1.03]
Presenility		30	33.5	0.90	[0.60,1.28]			4	2.99	1.34	[0.36,3.43]
Demyelinating diseases in CNS		4	2.11	1.90	[0.51,4.86]			1	0.54	1.86	[0.02,10.32]
Parkinson’s disease		64	71.5	0.90	[0.69,1.14]			4	6.40	0.62	[0.17,1.60]
Cerebral palsy		45	52.5	0.86	[0.62,1.15]			8	5.16	1.55	[0.67,3.06]
Epilepsy		148	196.2	0.75	[0.64,0.89]			19	31.68	0.60	[0.36,0.94]
Motor neuron diseases (non-ALS)		5	1.82	2.75	[0.88,6.41]			0	0.22	0	[0.00,16.80]
ALS		15	8.7	1.72	[0.96,2.83]			0	0.82	0	[0.00,4.50]
Spinal medullary disease		13	21.29	0.61	[0.32,1.04]			3	2.65	1.13	[0.23,3.31]
<i>Relative risk of neurological diseases among 24,850 men employed in Danish utility companies by average estimated level of EMF exposure, adjusted for age, calendar period and duration of employment</i>											
		Background ($<0.09\text{ }\mu\text{T}$)		Low ($0.10\text{--}0.29\text{ }\mu\text{T}$)		Medium ($0.30\text{--}0.99\text{ }\mu\text{T}$)		High ($\geq 1.0\text{ }\mu\text{T}$)		Unknown	
		N	RR	RR	95% CI	RR	95% CI	RR	95% CI	RR	95% CI
Disease (ICD-8)											
Senile dementia		122	1.00	1.00	[0.51,1.95]	1.15	[0.60,2.19]	1.43	[0.74,2.77]	1.51	[0.78,2.94]
Presenility		30	1.00	0.68	[0.20,2.34]	0.72	[0.21,2.48]	0.92	[0.25,3.42]	1.21	[0.34,4.32]
Parkinson disease		64	1.00	0.89	[0.42,1.87]	0.68	[0.31,1.49]	0.64	[0.26,1.54]	0.72	[0.29,1.79]

Study	Design	Exposure	Outcomes	Limitations		
Cerebral palsy	45	1.00	0.50 [0.16,1.54]	0.88 [0.33,2.39]	0.78 [0.25,2.42]	2.57 [0.92,7.19]
Epilepsy	148	1.00	1.51 [0.78,2.95]	1.50 [0.77,2.94]	2.03 [1.02,4.05]	1.61 [0.79,3.29]
Motor neuron disease	20	1.00	0.86 [0.16,4.71]	1.27 [0.26,6.32]	1.56 [0.29,8.53]	1.90 [0.33,11.13]
Spinal medullary disease	13	1.00	1.35 [0.14,13.04]	1.35 [0.14,12.97]	0.81 [0.05,12.96]	3.96 [0.43,36.59]
Summary						
Overall, there was an increased risk of senile dementia and motor neuron diseases (although differences were not statistically significant). The authors speculated that this may be associated with ‘above-average’ levels of exposure to magnetic fields. The incidences of Parkinson’s disease, Alzheimer’s disease, and other diseases of the CNS were not associated with exposure to ELF. The authors note that there was a decreased risk of epilepsy compared with the general population, which was likely related to a healthy worker effect.						
Johansen, Feychting et al. (2002)†	Retrospective cohort study. Investigators attempted to examine concerns about potential cardiovascular effects of occupational exposure to ELF. A cohort of approximately 24,000 men who worked in utility companies in Denmark (between 1900 and 1993) was linked to the nationwide, population-based Danish Pacemaker Register, and the numbers of persons who had undergone pacemaker implantation between 1982 and 2000 were compared with corresponding numbers in the general population.	Exposure to ELF in the 50–60 Hz frequency band. For each of the 475 combinations of job titles/work areas, an average level of exposure to 50 Hz ELF during a working day was assigned. These were also categorised into ELF (background exposure (≤0.09 μT), medium exposure (0.1–0.99 μT), and high exposure (≥1.0 μT)).	Incidence ratios for pacemaker implantation.	Awareness of exposure and observer bias in level or intensity of determining the outcome from registers. The study addresses only those heart diseases that require implantation of a pacemaker. Assessment of exposure was not obtained from individual data. No information about other exposures or lifestyle factors associated with cardiovascular disease (cigarette smoking, diet or physical activity) was collected, so the possibility of confounding cannot be excluded.		

Study	Design		Exposure		Outcomes		Limitations	
Results								
Standardised incidence ratios for pacemaker implantation during the period 1982–2000 among 24,056 men employed ≥3 months at a utility company in Denmark during 1900–1993, by average estimated level of exposure to electromagnetic fields at work and duration of employment								
	Background exposure (≤0.09 μT; n=20)		Medium exposure (0.1–0.99 μT; n=61)		High exposure (>1.0 μT; n=23)		Unknown (n=31)	
	Obs/Expt	SIR [95% CI]	Obs/Expt	SIR [95% CI]	Obs/Expt	SIR [95% CI]	Obs/Expt	SIR [95% CI]
Employment duration, years								
0–9	-/0.65	-	3/2.64	1.14 [0.2,3.3]	-/0.86	-	2/0.77	2.60 [0.3,9.4]
10–19	-/2.59	-	14/9.91	1.41 [0.8,2.4]	3/3.32	0.90 [0.2,2.6]	7/4.38	1.60 [0.6,3.3]
≥20	20/14.86	1.35 [0.8,2.1]	44/60.97	0.72 [0.5,1.0]	20/18.86	1.06 [0.7,1.6]	22/20.41	1.08 [0.7,1.6]
Total	20/18.10	1.11 [0.7,1.7]	61/73.51	0.83 [0.6,1.1]	23/23.04	1.00 [0.6,1.5]	31/25.55	1.21 [0.8,1.7]
Relative risk of pacemaker implantation among 24,056 men employed ≥3 months at a utility company in Denmark during 1990–1993, by average estimated level of ELF exposure at work ^a , adjusted for age calendar year and duration of employment								
	Background exposure (≤0.09 μT; n=20)		Medium exposure (0.1–0.99 μT; n=61)		High exposure (>1.0 μT; n=23)		Unknown (n=31)	
	RR		RR [95% CI]		RR [95% CI]		RR [95% CI]	
	1.0 ^b		1.6 [0.6,1.87]		0.89 [0.5,1.63]		1.06 [0.61,1.87]	
^a p for trend = 0.7; ^b Reference category								
Summary								
Overall, there was no statistically significant increased frequency of pacemaker implantation among employees: 135 subjects received implants, yielding a risk estimate of 0.96 (95% CI [0.81, 1.14]). No clear dose–response pattern emerged with increasing ELF exposure or with duration of employment. A Poisson regression analysis was conducted, which showed no statistically significant increased risk in the group with high exposure compared with the group with background exposure, and there was no observed trend in the risk estimate when workers were compared according to their level of occupational exposure to								

Study	Design	Exposure	Outcomes	Limitations
electromagnetic fields (p=0.7).				
Johansen and Olsen (1998) [†]	Johansen and Olsen conducted 8 separate cohort studies among Danish utility workers to examine any increased risk of cancer, ALS, multiple sclerosis, CNS diseases and other chronic disorders, as well as cause-specific mortality associated with ELF. All employees were followed up in several registers. Risk of disease was analysed in relation to occupational ELF exposure, latency, and duration of employment. A specific job-exposure matrix was developed and validated by comparison with direct measurements of ELF during a workday.	Disease among employees exposed to ELF (50-Hz) in the Danish utility industry.	Any increased risk of cancer, ALS, multiple sclerosis, CNS diseases and other chronic disorders, and cause-specific mortality.	

Results									
<i>Observed numbers of deaths and standardised mortality ratios by selected causes of death and time since first employment among 21,236 men with ≥3 months employment at a utility company in Denmark during 1900–1993</i>									
		Time since first employment							
		0–9 years		10–29 years		>30 years			
	Observed	SMR	Observed	SMR	Observed	SMR	Observed	SMR	
Cause of death									
All causes	3540	0.96	305	0.82	1869	0.97	1366	0.98	
All malignant neoplasms	1070	1.1 ^a	71	0.8	576	1.1	423	1.1 ^a	

Study	Design			Exposure		Outcomes		Limitations
Leukaemia	30	0.9	3	0.7	13	0.8	14	1.2
Breast cancer	2	1.6	0	0	1	1.5	1	2.2
Brain cancer	4	1.4	1	1.7	0	0	3	4.5
Lung cancer	343	1.1 ^a	22	0.9	199	1.2 ^a	122	1.1
Pleural cancer	14	2.3 ^a	0	0	8	2.3	6	2.9 ^a
Neurological disorders								
ALS	14	2.0 ^a	0	0	8	2.0	6	2.7 ^a
Parkinson's disease	6	0.8	0	0	3	0.8	3	0.8
Multiple sclerosis	3	0.4	0	0	2	0.5	1	0.7
Senile dementia	4	0.5	0	0	3	1.0	1	0.2
Presenile dementia	2	0.9	0	0	1	0.8	1	1.0
Behaviour-related causes								
Accidents caused by								
Electricity	10	18.1 ^a	2	8.0	8	29.2 ^a	0	0
Alcoholism	21	1.0	8	2.2	12	0.9	1	0.3
Motor vehicles	49	0.9	19	1.0	22	0.9	8	0.9
Suicide	133	0.9	36	0.9	82	1.0	15	0.8
Cardiovascular disorders								
Acute myocardial infarction	713	1.0	54	0.9	385	1.0	274	1.0
Cardiac arteriosclerosis	300	0.9	12	0.8	151	1.0	137	0.9
Other heart diseases	152	0.9	9	0.7	78	0.9	65	0.9
Cerebrovascular disease	207	0.8	14	1.0	101	0.8	92	0.8
Respiratory disorders								
Bronchitis and emphysema	159	1.0	7	0.9	87	1.1	65	1.0

Study	Design		Exposure		Outcomes		Limitations	
Asthma	4	0.4	0	0	3	0.5	1	0.3
Other specified causes	644	0.9	67	0.7	329	0.9	248	1.0
Unknown cause	49	0.9	4	0.7	18	0.9	25	1.0
^a p<0.05								
<i>Observed numbers of deaths and standardised mortality ratios by selected causes of death and estimated average workplace exposure to 50 Hz magnetic fields among 21,236 men with ≥3 months employment at a utility company in Denmark during 1900–1993</i>								
	Background exposure (≤0.09 μT)		Low exposure (0.10–0.29 μT)		Medium exposure (0.30–0.99 μT)		High exposure (>1.0 μT)	
	Observed	SMR	Observed	SMR	Observed	SMR	Observed	SMR
Cause of death								
All causes	474	0.79	1063	0.93	1134	0.96	869	1.12 ^a
All malignant neoplasms	151	0.9	301	1.0	366	1.2 ^a	252	1.2 ^a
Leukaemia	2	0.4	7	0.7	15	1.4	6	0.9
Breast cancer	0	0	1	2.6	0	0	1	4.0
Brain cancer	0	0	2	2.1	2	2.1	0	0
Lung cancer	47	1.0	88	1.0	117	1.2 ^a	91	1.4 ^a
Pleural cancer	0	0	2	1.0	7	3.5 ^a	5	4.0 ^a
Neurological disorders								
ALS	1	0.9	4	1.9	5	2.3	4	2.8
Parkinson's disease	1	0.7	3	1.3	1	0.4	1	0.6
Multiple sclerosis	0	0	0	0	2	0.9	1	0.8
Senile dementia	0	0	1	0.4	2	0.8	1	0.6
Presenile dementia	0	0	1	1.4	1	1.3	0	0
Behaviour-related causes								

Study	Design		Exposure		Outcomes		Limitations	
Accidents caused by								
Electricity	0	0	2	10.1 ^a	5	26.9 ^a	3	30.8 ^a
Alcoholism	1	0.4	10	1.5	6	0.9	3	1.1
Motor vehicles	4	0.5	24	1.3	12	0.7	9	0.9
Suicide	19	1.0	37	0.8	41	0.9	36	1.4
Cardiovascular disorders								
Acute myocardial infarction	96	0.8	225	1.0	232	1.0	160	1.0
Cardiac arteriosclerosis	38	0.7	98	1.0	79	0.8	85	1.2
Other heart diseases	27	0.9	35	0.7	52	1.0	38	1.1
Cerebrovascular disease	24	0.6	68	0.9	61	0.8	54	1.0
Respiratory disorders								
Bronchitis and emphysema	20	0.8	50	1.1	48	1.0	41	1.2
Asthma	2	1.1	1	0.3	1	0.3	0	0
Other specified causes	82	0.7	189	0.8	203	0.9	170	1.1
Unknown cause	8	0.9	14	0.8	17	0.9	10	0.9
^a p<0.05								
Summary								
Linkage with the Danish Cancer Register did not identify increased risks for those cancers suggested <i>a priori</i> to be associated with exposure to ELF, including leukaemia, brain tumours and breast cancer. Linkage with the National Mortality Register revealed a significantly increased overall mortality rate from ALS, with an increasing trend with duration of employment and ELF exposure. In addition, a significantly increased mortality rate from electric accidents was observed. It was hypothesised that the observation of increased mortality from ALS was associated with exposure to ELF or electric shocks. No increased mortality rate from cardiovascular or cerebrovascular disease was observed. Linkage of the cohort with the Multiple Sclerosis Register revealed an increased risk of multiple sclerosis, which was not, however, significant. Linkage with the Pacemaker Register showed no increased risk of severe arrhythmia-related heart disease.								

Study	Design	Exposure	Outcomes	Limitations
Ahlbom et al. (2001)	Comprehensive non-systematic review. 18 studies included on ELF and childhood cancer—17 case-control studies (2 nested) and one cohort study. 7 studies included on ELF and amyotrophic lateral sclerosis (ALS)—5 case-control and 2 cohort studies. 5 studies included on ELF and Alzheimer’s disease—4 case-control studies and one cohort study. 5 studies on ELF and suicide—2 case-controls and 3 studies calculated the standardised or proportional mortality ratio. 6 studies on ELF and depression—5 cross-sectional and one case-control study. Authors presented a narrative discussion of studies on the association between occupational/residential exposures to ELF and either cardiovascular risk or reproductive adverse effects, but did not specify the number of studies.	ELF from a range of sources including residential (close proximity to power lines) and occupational (e.g. video display terminals) ELF exposures. Authors considered ELF as time-varying electric and/or magnetic fields <300 Hz; however, most included studies, where specified, assessed magnetic fields <60 Hz.	Various cancers and ALS.	The authors caution that the observed associations from reviewed studies are highly uncertain due to potential for bias and confounding. There was uncertainty regarding the methods used to measure and categorise ELF, leading to potential misclassification and difficulty in comparing/combining studies.
Results <i>Pooled analysis of studies (n=9) on ELF exposure and childhood leukaemia</i>				

Study	Design	Exposure	Outcomes	Limitations
	Summary residential ELF exposure <0.4 µT	Estimated residential ELF exposure ≥0.4 µT		
Cases, n				
Observed	3,203	44		
Expected	NR	24.2		
Excess	NR	19.8		
Controls, n	10,338	62		
RR [95% CI]	NR ^a	2.0 [1.27,3.13]		
^a While no data were provided, the authors reported that the risk was found 'to be near the no-effect level'.				
<i>Pooled analysis of studies (n=14) on ELF exposure and ALS</i>				
Pooled studies	No. of studies	RR [95% CI]		
All	7	1.5 [1.2,1.7]		
Clinically and ALS society-based	3	3.3 [1.7,6.7]		
Mortality registry and census-based	2	1.3 [1.1,1.6]		
Utility cohort studies	2	2.7 [1.4,5.0]		
Summary				
Among the evaluated outcomes, the one for which there was most evidence of an association was childhood leukaemia in relation to postnatal exposures above 0.4 µT. The relative risk was 2.0 (95% CI [1.27, 3.13]) from a large pooled analysis. There was some evidence of an association between ALS with occupational ELF exposure.				

Abbreviations: RCT = randomised controlled trial; µT = microtesla; ELF = extremely low-frequency electromagnetic field(s); CNS = central nervous system; mT = millitesla; ELF = extremely low frequency electromagnetic field(s); ALS = amyotrophic lateral sclerosis; SWS = slow wave sleep; SWA = slow wave activity; REM = rapid eye movement; ANOVA = analysis of variance; ACTH = adrenocorticotrophic hormone; GH = growth hormone; ICD-8 = International Classification of Diseases = Revision 8; RR = relative risk; CI = confidence interval; SMR = standardised mortality ratio; SIR = standardised incidence ratio; NR = not reported; SE = standard error; dB = decibels; NS = not (statistically) significant

† The Johansen ELF studies are based on the same cohort, with individual publications reporting different outcomes or sets of outcomes.

SUMMARY: DIRECT, MECHANISTIC AND PARALLEL EVIDENCE ON EMR

SQ5. Is there any reliable evidence of an association between electromagnetic radiation from wind turbines and adverse health effects?

No studies were identified that considered the effect of ‘electromagnetic radiation’, as it relates to wind turbines, on human health.

BQ2. By what specific physical emissions might wind turbines cause adverse health effects? (EMR)

Mechanistic studies indicate that the effects of external exposure to EMR on the human body and its cells depend mainly on the EMR frequency and strength (WHO 2002). It is known that the strength of an alternating magnetic field rapidly decreases as distance from the source increases (WHO 2012b). ELF EMR can produce eddy currents in human tissue. Since biochemical mechanisms and nerve transmission utilise electric impulses, exposure to ELF EMR could interfere with electrical currents that are vital to normal bodily function if the person is in close proximity to the source of the EMR.

BQ3. For each such emission, what is the level of exposure from a wind turbine and how does it vary by distance and characteristics of the terrain separating a wind turbine from potentially exposed people?

In wind farms EMR is emitted from grid connection lines, underground collector network cabling, electrical transformers and turbine generators. However, there are scant data (one industry example only (Windrush Energy 2004)) on the magnitude and/or level (quantity) of ELF EMR present in the vicinity of wind turbines. The available industry data suggests that the ELF EMR levels near wind farms are likely to be within the range of ELF EMR emitted by household appliances.

SUMMARY (CONT.)

BQ4. Is there basic biological evidence, or evidence from research into other circumstances of human exposure to electromagnetic radiation, that make it plausible that wind turbines cause adverse health effects?

The applicability of the available parallel evidence on EMR to the wind farm context is uncertain. Concerns regarding the safety of EMR were raised with the publication of an early study reporting an association between the risk of childhood leukaemia and the degree of EMR exposure from electricity transmission lines (Wertheimer & Leeper 1979). Research has also been conducted on possible associations between occupational EMR and cancer or cardiovascular, neurological/psychological and reproductive diseases. However, apart from the study of childhood leukaemia, results from these EMR studies are characterised by a high degree of heterogeneity and are all considered to be inconclusive with respect to a causal association between EMR exposure and human health effects (Ahlbom et al. 2001).

WIND TURBINE EXPOSURE AND HUMAN HEALTH EFFECTS ASSESSED AGAINST MODIFIED BRADFORD HILL CAUSALITY GUIDELINES

The direct, mechanistic and parallel evidence collated for this review was considered within the causality framework offered by the modified Bradford Hill Guidelines. Pre-specified indicators were used to determine whether there is a probable cause-and-effect relationship between exposure to wind turbine emissions and adverse health effects. Causation could not be demonstrated (Table 39).

The isolated reports of adverse health effects in the direct evidence could not be convincingly attributed to wind farm exposure. This was mainly due to the cross-sectional design of the available studies, inconsistent findings between studies, and the potential impact of bias, plausible confounders and chance on the observed results. Although it was clear that self-reported adverse health effects occurred in the vicinity of wind turbines, these effects did not differ by the purported degree of exposure to wind turbine noise i.e. estimated SPL (dose-responsiveness). Degree of exposure, as measured by *distance* from a wind turbine (dichotomised into 'near' and 'far') did affect mental health in one small study, although this finding was inconsistent with the non-statistically significant results reported from four other studies that measured stress, irritability, anxiety and depression in study participants.

A dose-response relationship was apparent between wind turbine proximity and the possibly health related effects of self-reported sleep quality, sleep disturbance and quality of life. However, there is a possibility that the associations with sleep quality, sleep disturbance and quality of life are confounded by annoyance and other factors that determine it. Annoyance appeared to be more related to turbine visibility and lack of economic benefit than to wind turbine noise⁴⁴ (see page 163 for further detail).

It could not be determined from the scant evidence available whether any of the effects studied except, perhaps, sleep disturbance would be reversible in the absence of wind turbine exposure. Equally, it was uncertain whether there is a clear mechanism of action by which wind turbine exposure can cause adverse health effects. The mechanistic evidence reviewed did indicate that shadow flicker and ELF EMR exposure could theoretically have physiological impacts on humans; that is, respectively, epileptic seizures in photosensitive individuals and possibly childhood leukaemia. However, the type of shadow flicker and extent of ELF EMR exposure produced by wind turbines is likely to be different from that considered in the parallel research evidence that was conducted in the laboratory or field setting. The flicker frequency and colour investigated in the laboratory setting was different from that produced by wind turbines. Similarly, from the scant evidence available it would appear that the degree of ELF EMR exposure around wind turbines was unlikely to be higher

⁴⁴ measured by estimated SPL

than that produced by general electrical appliances. Further evidence is therefore needed to determine possible mechanisms of action.

There was no scientifically accepted mechanism by which ILFN could cause adverse health effects in humans in the limited mechanistic evidence collated for this review. Further, given the recent South Australian Environment Protection Authority report on noise levels in the vicinity of wind turbines (Evans, Cooper & Lenchine 2013), the available laboratory (parallel) evidence is unlikely to be applicable as it primarily tested ILFN at high SPLs (>80 dB) and found inconsistent effects of ILFN on the intermediate physiological measures taken from study participants. Health outcomes were not measured.

Table 39 Assessing the causal hypothesis using the modified Bradford Hill Guidelines

Type of evidence	Causal indicator	Demonstrated?
Direct <i>(Assesses the impact of wind turbine exposure on health outcomes)</i>	Size of effect not attributable to plausible confounding	No. Where associations with wind turbine exposure were observed, they were generally weak and attributable to other factors.
	Appropriate temporal proximity—cause precedes effect and effect occurs after a plausible interval	No. All studies were cross sectional and it was not determined whether exposure preceded onset of observed effects.
	Appropriate spatial proximity—health effect occurs at same site as exposure	Yes. Self-reported health effects occurred near wind turbines.
	Dose-responsiveness	Uncertain. There was no dose-response effect for health effects but there was evidence of increases in health-related (sleep disruption/quality of life) and relevant non-health-related effects (annoyance) by degree of estimated noise exposure.
	Reversibility	Uncertain. One study reported reversibility of effect on sleep when moving away from proximity to wind turbines
Mechanistic <i>(Investigates the mechanisms that are</i>	Evidence for a mechanism of action (biological, chemical, mechanical)	Uncertain. Plausible mechanisms were not demonstrated in the epidemiological studies or the few

Type of evidence	Causal indicator	Demonstrated?
<i>supposed to connect wind turbine exposure to health outcomes)</i>		experimental studies in humans that reported on health or relevant non-health endpoints.
	Coherence	Uncertain. Relevant current scientific knowledge as to possible mechanisms was not reviewed to the extent needed to make a judgement as to coherence.
Parallel <i>(Comprises related studies that have similar results)</i>	Replicability	No. Similar study protocols were used across some wind turbine studies (e.g. SWE-00, SWE-05, NL-07) but adverse health effects were not replicated. Health effects were not measured in the “emission” laboratory and field studies.
	Similarity	No. The exposures considered in the laboratory and field studies were either not reported or differed from those likely to be produced by wind turbines.
	Applicability	Possible. Since European and North American countries have a longer history of, and more extensive, wind turbine development and a greater population density than Australia, it is possible that wind turbine exposure in Australia is qualitatively and quantitatively different from the exposures contributing most evidence.

Source: Howick, Glasziou and Aronson (2009)

ALTERNATIVE EXPLANATIONS FOR REPORTED ASSOCIATIONS

BQ6. IS THERE EVIDENCE THAT THERE ARE CONFOUNDING FACTORS OR EFFECT MODIFIERS THAT MIGHT EXPLAIN THE ASSOCIATION OF WIND TURBINES WITH ADVERSE HEALTH EFFECTS?

Attitudes towards wind farms

The studies included in the systematic review consistently found that proximity to wind turbines was related to annoyance, with three studies showing that level of annoyance is a stronger predictor of sleep disturbance, tension/stress and irritability than estimated wind turbine noise exposure *per se*.

Those who had a negative attitude to wind farms in general had 13.4 times the odds of being annoyed by noise from wind turbines than those who were not negative about wind farms (95%CI 6.03, 29.59) (Pedersen et al. 2007). Given that these results are from a cross-sectional study, it is not possible to determine whether attitudes to wind farms were stable and a predictor of annoyance, or whether noise annoyance had an impact on general attitudes towards wind farms. The association between how people view the appearance of wind turbines ('visual attitude', i.e. beautiful or ugly) and annoyance was strong, with a negative visual attitude increasing the odds of annoyance by more than 14 times (OR=14.4, 95%CI 6.37, 32.44).

Visibility of turbines

The visibility of turbines strongly influenced whether respondents were annoyed by the noise of wind turbines or not. When individuals could see at least one wind turbine, they had almost 11 times the odds of being annoyed by the sound of it (see Table 24) (Pedersen et al. 2007). This association was strongly influenced by the visual attitude of the individuals; that is, whether they considered wind turbines to be aesthetically beautiful and natural, or ugly and unnatural. Visual attitude was a stronger determinant of noise annoyance in those who could see wind turbines than in those who could not (Pedersen & Larsman 2008).

Financial gain from the site of turbines

Pedersen et al. (2009) reported that very few people who gained financially from wind turbines reported annoyance due to noise (3/100), although perception of the noise level was the same regardless of financial gain. They hypothesised that those who benefit financially may have a positive appraisal of the sound as it signifies profit, and also that those who are not benefiting financially from the wind turbines may have resentment against their neighbours who are, which could increase the difference in the levels of annoyance.

Community decision-making on site of turbines

There was no direct evidence that community decision-making regarding the site of wind turbines influenced reported health outcomes within that community. However, Ellenbogen et al. (2012) note that effective public participation in, and direct benefits from, wind energy projects (such as receiving electricity from the neighbouring wind turbines) have been shown to result in less annoyance in general and better public acceptance overall. This would be consistent with the findings of van den Berg et al. (2008), who reported that the level of annoyance with wind turbine noise was lower in people who received financial benefit from the wind farm. They hypothesised that one of the mechanisms of this finding may be that those who gained financially may have had a measure of control over the location of the wind turbines.

Age and design of turbines

None of the studies that assessed the impact of wind turbines on health assessed whether the age or design of the turbine influenced the results. However, it is noted from other sources that older wind turbines that used gears were noisier than newer turbines, which do not have a gear box (Hall, Ashworth & Shaw 2012).

Nocebo effect

In the limited literature linking adverse health outcomes to wind farms, there was no evidence identified that considered health effects or related non-health effects (e.g. annoyance) could be due to expectation effects, or nocebo effects (negative placebo effects) (Häuser, Hansen & Enck 2012). It has been reported that soon after a wind farm project has been made public, local residents have been contacted by outside groups who provide information on the range of supposed negative effects of wind farms (Hall, Ashworth & Shaw 2012). There is therefore a risk that prior expectations towards wind farms could be negative, increasing the likelihood of individuals experiencing adverse effects (i.e. through a nocebo effect), either being sensitive to the effects they have been warned about, or attributing normally occurring health problems to the presence of wind turbines.

LIMITATIONS IN THE EVIDENCE-BASE AND SUGGESTIONS FOR FURTHER RESEARCH

Although a very comprehensive search for both unpublished ('grey') and published ('black') literature on the adverse health effects of wind turbines was conducted, it cannot be excluded that some evidence may have been missed. Study authors may have chosen not to submit their work to a public forum or those responsible for research publication may have chosen not to publish the work. This can occur when the result of a study is a 'null result' i.e. there is no effect found. This type of publication bias tends to be a problem that affects the 'black' literature.

Present evidence on the association of exposure to wind turbines and adverse health effects appears to be very limited. There is no consistent evidence that adverse health effects are caused by exposure to wind turbine noise. There is, though, consistent—albeit probably confounded—evidence that noise from wind turbines is associated with annoyance, and reasonably consistent evidence that it is associated with sleep disturbance and poorer quality of life. None of this evidence is sufficient to establish a cause-and-effect relationship. While no research has directly addressed the association between infrasound from wind turbines and health effects, the possibility of such an association cannot be excluded on present evidence.

While, *a priori*, the probability that there are material health effects consequent on residence at a reasonable distance from wind turbines could be judged as low, concern has been expressed by people who live near wind turbines about perceived impacts on their health (Senate Community Affairs References Committee 2011). Given these subjective experiences and the limited research evidence summarised above, further and better research on the relationship between noise from wind turbines and health, sleep and quality of life is warranted.

There are several elements of research that would greatly assist making stronger conclusions regarding the health effects of wind farms. These aspects include:

- comparative data; that is, measuring health outcomes in groups who have not been exposed to wind turbines and comparing it with data collected from groups who have been exposed to wind turbines, ideally collected in the same time period and at the same time points.
- prospective collection of data to enable temporal effects to be examined; that is, measuring the health status of residents prior to wind turbine installation and again afterwards
- response from a sample representative of all those exposed (i.e. not only those who have a health complaint but, ideally, at least a 70% response rate from those approached), in order to be externally generalisable
- large enough samples to allow confidence that the effects are not due to chance

- health examinations carried out by professionals rather than self-reported, to increase the objectivity of outcomes
- health effects reported with participants and interviewers masked to study intent, to minimise bias
- objective measurements of exposure (such as volume of noise at the place of residence, distance to nearest wind turbine), rather than modelled measurements
- statistical analyses adjusted for cluster effects and multiple comparisons.

One of the largest identified problems with the literature is the sample selection bias in the studies. Although the participants may have been recruited from relevant populations, and the better quality studies have attempted to gain data from a cross-section of people exposed and non-exposed to wind farms, the response rates were very poor. There is, therefore, an increased probability of biased comparisons between exposed and unexposed groups and a high risk that those who responded to the surveys are not representative of the whole community (both exposed and non-exposed). Rather, they have self-selected to respond to the survey because they are experiencing adverse events. The field of wind farm research would be greatly improved by comparative research that uses a mix of strategies to improve rates of response. A reasonable study design would be a prospective cohort study, retrieving data from individuals who live in areas where a wind farm is being proposed to be built and from similar communities where a wind farm is not going to be built.

A simpler study design, which would also provide useful information, would be a historical control study, comparing data before and after the introduction of a wind farm. Health data could be gathered from sources such as from general practitioners' records (e.g. the BEACH database), to see whether the rates of health complaints go up with the introduction of the wind farm, after adjustment for potential confounders. Alternatively, a retrospective cohort study could be conducted where data are also obtained from a control group over the same time period, with comparative baseline rates of health complaints and similar demographics to control for the effect of time.

ONGOING RESEARCH

International research

The limited availability of robust, peer-reviewed scientific studies on the health effects of wind turbines/farms has stimulated some government health authorities, such as Health Canada, to begin conducting independent research. Health Canada argues that lack of prevalence data on community complaints and self-reported health impacts from studies with strong methodological designs are significant barriers to providing advice on noise impacts from wind turbines. If such data were available, it is likely that understanding of the

concern about wind turbine noise among affected communities would be improved. This could then be compared with the prevalence of similar health concerns in communities that are not situated near wind turbines (Health Canada 2012).

Health Canada is now undertaking a cross-sectional field study to compare self-reported health impacts and symptoms of illness (25-minute interviews) against *objective* biomarkers of stress and the sound levels produced by wind turbines. The expected publication date for this study is late 2014 and will include 2000 dwellings at setback distances ranging from less than 500 m to greater than 5 km from 8–12 wind farms. Collected data will be correlated with model estimates of wind turbine noise (validated against actual measurements) so that potential relationships to reported health symptoms can be reliably determined. Specifically, the objective data under evaluation will include (Health Canada 2012, 2013):

- automated blood pressure measurements;
- 90-day retrospective cortisol levels based on hair samples;
- actigraphic measurements of sleep over 7 consecutive days (synchronised with wind turbine operational data and estimates of indoor wind turbine sound exposure); and
- environmental sound measurements, including low-frequency noise, inside and outside a subsample of homes (to validate parameters for accurate sound level modelling).

Importantly, unlike the peer-reviewed literature considered in our review, Health Canada will undertake measures to mitigate the effects of participation bias that are likely to influence the results in the absence of a response rate below the 70–75% range. By targeting all dwellings within the highest wind turbine sound exposure categories, random sampling of dwellings at more distant sound exposure categories, and random sampling of the one subject per home that participates in the survey, it is anticipated that bias due to self-selection should be reduced as much as possible. As part of the questionnaire process, the study protocol specifies collection of information that will allow Health Canada to determine the extent to which bias may influence results. The potential for entry of bias that relates to time of day when visits are made to conduct questionnaires has been planned for by specifying that home visits should be made at all times of the day. Statistical analyses to assess any systematic differences that may exist in subjects that participate fully, partially or not at all are also planned. For example, an analysis by distance to the closest turbine can be done to reveal a potential bias in the sample. Despite these measures, however, Health Canada has acknowledged that the extent to which non-response may impact their study cannot be determined *a priori*.

Australian research

The Environment Protection Authority of South Australia (Evans, Cooper & Lenchine 2013) has conducted research on the levels of infrasound near wind farms and other environments, with further study of similar design ongoing. Environments other than those within the vicinity of wind farms were included in order to compare background infrasound

levels with the levels that are measured in areas near wind farms when turbines are both operational and non-operational. While these findings are an important part of ongoing research, the relationship of these levels with objective measures of health is yet to be studied in Australia. Objective measures of exposure other than sound (i.e. flicker and ELF EMR) are also lacking, and exploration of these exposures and health status (pre-exposure and post-exposure) may be helpful in drawing conclusions about whether there is a relationship between wind turbines and health. As suggested above, the study design that would be most useful is a prospective cohort study. A historical control study could also be designed in order to examine potential associations between observed changes in health status and exposure while reducing, or at least quantifying, the likelihood that factors other than the exposure are confounding the findings or introducing bias. An approach similar to the Health Canada study on wind turbines and health could also be adopted, noting transparently the limitations of this approach. Following availability of robust, relatively homogenous data from Australia, Canada and elsewhere, the results of a possible pooled analysis of health outcomes would be useful for informing future policy recommendations.

CONCLUSIONS

In summary, the systematic review found no consistent evidence that noise from wind turbines, whether estimated in models or using distance as a proxy, is associated with self-reported human health effects. The quality and quantity of the available evidence was limited.

Wind turbine noise—whether estimated in models or using distance as a proxy—was associated with annoyance, and often associated with sleep disturbance and poorer sleep quality and quality of life. However, there are concerns as to the strength and validity of these reported associations in the available evidence (see below).

Shadow flicker produced by wind turbines was found to be associated with annoyance in one small study, but health effects were not measured. There were no studies identified that investigated the impact on health of the electromagnetic radiation produced by wind turbines.

Do wind turbines cause adverse health effects in humans?

To evaluate the strength of the evidence for a cause-and-effect relationship between wind turbines and adverse human health and health-related effects, the totality of the evidence was assessed in terms of the modified Bradford Hill Guidelines (Table 5, page 40).

The reported effects in the studies did occur near wind turbines (spatial proximity). However, with the exception of annoyance, sleep quality or disturbance and quality of life—which are possibly related—there was no consistent association between adverse health effects and estimated noise from wind turbines. Any isolated associations that were observed could have been due to plausible confounding or a spurious result from undertaking multiple statistical tests. It was not possible to determine whether any of the associations of wind turbine exposure with self-reported health effects occurred before or after first exposure to wind turbines (temporal proximity) because of the cross-sectional nature of the available studies. From the reported data, there was no dose–response relationship observed between estimated noise exposure (modelled SPL or distance from a wind turbine) and direct human health effects.

A dose–response relationship between wind turbine proximity and possibly health-related effects such as sleep disturbance, poor sleep quality and quality of life was apparent; that is, these effects were less common as the estimated SPL reduced or distance from wind turbines increased. However, the studies measuring sleep disturbance, sleep quality and quality of life often did not control for factors that may have confounded the results, such as annoyance and other factors that determine it. In the studies measuring noise annoyance there was a stronger association with turbine visibility or lack of economic benefit than with estimated sound pressure level. Evidence of reversibility was present in one small study. Participants in this study recalled less sleep disturbance when they were away from wind

turbines. The participants knew the purpose of the study was to investigate wind turbine noise.

The information addressing the background questions did not strengthen the evidence base for an association between health, or health-related, effects and exposure to wind turbines. Possible mechanisms by which wind turbines could harm human health—and which were coherent with existing scientific theory—were plausible for shadow flicker and ELF EMR exposure, but were of uncertain applicability to the wind turbine context. A mechanism by which ILFN could harm human health could not be determined. There was no consistent association observed between ILFN and intermediate physiologic effects (e.g. blood pressure) in the laboratory setting. Health outcomes were not measured.

The quality and quantity of evidence available to address the questions posed in this review was limited. The evidence considered does not support the conclusion that wind turbines have direct adverse effects on human health, as the criteria for causation have not been fulfilled. Indirect effects of wind farms on human health through sleep disturbance, reduced sleep quality, quality of life and perhaps annoyance are possible. Bias and confounding could, however, be possible explanations for the reported associations upon which this conclusion is based.

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GLOSSARY AND ABBREVIATIONS

Glossary⁴⁵

<i>A priori</i>	Relating to or denoting reasoning or knowledge that proceeds from theoretical deduction rather than from observation or experience.
Aerodynamic sound	Sound generated by turbulent motion or aerodynamic forces interacting with surfaces; for <i>wind turbines</i> , generated by the interaction of the blade trailing-edge, tip or surface with air turbulence (see Table 8 for a full description).
Amplitude	A measurement of the energy carried by a wave—the greater the amplitude of the wave, the higher the level of energy carried; for a sound wave, the greater the amplitude, the louder the sound.
Annoyance	An unpleasant mental state that is characterised by such effects as irritation and distraction from one’s conscious thinking.
ANOVA*	Analysis of variance: a statistical technique that isolates and assesses the contribution of categorical independent variables to the variance of the mean of a continuous dependent variable. The observations are classified according to their categories for each of the independent variables, and the differences between the categories in their mean values on the dependent variable are estimated and tested for statistical significance.
Association*	Statistical dependence between two or more events, characteristics or other variables. An association is present if the probability of occurrence of an event or characteristic, or the quantity of a variable, varies with the occurrence of one or more other events, the presence of one or more other characteristics, or the quantity of one or more other variables. An association may be fortuitous or may be produced by various other circumstances; the presence of an association does not necessarily imply a causal relationship. In epidemiological and clinical research, the terms association and relationship may often be used interchangeably.
Audibility threshold	Also known as the absolute threshold of hearing, it is the minimum sound level of a pure tone that an average ear with normal hearing can register with no other sound present.
Audible sound	Sound that can be detected normally by the human ear; sound that falls within the nominal frequency range of 20–20,000 Hz (upper

⁴⁵ All epidemiological terms (marked as *) in this Glossary have been defined using the International Epidemiological Association’s (IEA’s) *Dictionary of Epidemiology* (2008).

range limit declines with age) and with normal exposure levels.

Bias*	Systematic deviation of results or inferences from truth; processes leading to such deviation; an error in the conception and design of a study—or in the collection, analysis, interpretation, reporting, publication or review of data—leading to results or conclusions that are systematically (as opposed to randomly) different from the truth.
Biological plausibility*	The causal criterion or consideration that an observed, presumably causal, association is plausible on the basis of existing biomedical knowledge.
Black literature	An alternative term for peer-reviewed literature that has been published.
Blade glint	The visual effect of light reflecting off the rotating blade surface of a <i>wind turbine</i> ; can theoretically result in a stroboscopic effect to an observer.
Broadband sound	When a sound is produced by a broad range of frequencies, it is generally called broadband (such as sound from a waterfall).
Case series*	A collection of patients with common characteristics used to describe some clinical, pathophysiological or operational aspect of a disease, treatment or diagnostic procedure. A case series does not include a comparison group and is often based on prevalent cases and a sample of convenience. Common selection biases and confounding severely limit their power to make causal inferences.
Chance	The probability ⁴⁶ that an event will happen.
Coherence*	The extent to which a hypothesised causal association fits with pre-existing theory and knowledge (see <i>Modified Bradford Hill Guidelines</i>).
Cohort study*	The analytic epidemiological study in which subsets of a defined population can be identified who are, have been or, in the future may be, exposed or not exposed, or exposed in different degrees, to a factor or factors hypothesised to influence the occurrence of a given disease or other outcome. The main feature of cohort study is observation of large numbers over a long period (commonly years), with comparison of incidence rates in groups that differ in exposure levels; this study type may be retrospective or prospective.
Confidence interval (CI)*	The conventional form of an interval estimate, computed in statistical analyses, based on the theory of frequency probability. If the underlying statistical model is correct and there is no <i>bias</i> , a confidence interval derived from a valid analysis will, over unlimited

⁴⁶ The IEA *Dictionary of Epidemiology* (2008) states ‘possibility’ rather than ‘probability’; however, for the purposes of the current report we prefer ‘probability’.

	repetitions of the study, contain the true parameter with a frequency no less than its confidence level (often 95% is the stated level, but other levels are also used).
Confounder/plausible confounder	A factor (or plausible factor) that has an association with the exposure being investigated and an association with the outcome being measured within the data being used for the analysis.
Confounding*	Loosely, the distortion of a measure of the effect of an exposure on an outcome due to the association of the exposure with other factors (confounders) that influence the occurrence of the outcome. Confounding occurs when all or part of the apparent association between the exposure and the outcome is in fact accounted for by other variables that affect the outcome, and are not themselves affected by the exposure.
Cross-over study*	A method of comparing two (or more) treatments or interventions in which subjects, upon completion of one treatment, switch to the other; may be observational or experimental in design.
Cross-sectional study*	A study that examines the relationship between diseases (or other health-related characteristics) and other variables of interest as they exist in a defined population at one particular time. The presence or absence of disease, and the presence or absence of the other variables (or, if they are quantitative, their level), are determined in each member of the study population or in a representative sample at one particular time. The relationship between a variable and the disease can be examined (1) in terms of the prevalence of disease in different population subgroups defined according to the presence or absence (or level) of the variables, and (2) in terms of the presence or absence (or level) of the variables in the diseased versus the non-diseased. Note that disease prevalence rather than incidence is normally recorded in a cross-sectional study. The temporal sequence of cause and effect cannot necessarily be determined in a cross-sectional study.
Decibel (dB)	A unit of measure used to express the loudness of sound, calculated as the logarithmic ratio of sound pressure level against a reference pressure.
Direct evidence	Evidence directly or causally linking an exposure with a health outcome of interest through experimental evidence (randomised or non-randomised trial(s)) or observational evidence (see <i>Modified Bradford Hill Guidelines</i>).
Dose response*	An association between a given dose or set of doses (i.e. amount, duration, concentration) of an agent and the magnitude of a graded effect in an individual or a population; the relationship of observed outcomes (responses) in a population to varying levels of a protective or harmful agent such as a drug or an environmental contaminant.

Economic benefit	A benefit to a person, business or society that can be expressed numerically as an amount of money that will be saved or generated as the result of an action.
Effect modifier*	A factor that modifies the measure of effect of a putative causal factor under study. There is effect modification when the selected effect measure for the factor under study varies across levels of another factor. An effect modifier may modify different measures in different directions and may modify one measure but not another; also known as a modifying factor.
Electromagnetic field (EMF)	A three-dimensional area in which <i>electromagnetic radiation</i> is present or active.
Electromagnetic radiation (EMR)	Radiation that is a combination of electric and magnetic radiation (such as X-rays, ultraviolet, infrared, visible light and radio waves); transmitted in a wave-like pattern as part of a continuous spectrum of radiation.
Epilepsy	A neurological disorder marked by sudden recurrent episodes of sensory disturbance, loss of consciousness and/or convulsions associated with abnormal electrical activity in the brain.
Epileptogenic	Causing an epileptic seizure.
Exposed population/group*	In epidemiology the exposed group (or, simply, the exposed) is often used to connote a group whose members have been exposed to a supposed cause of a disease or health state of interest, or who possess a characteristic that is a determinant of the health outcome of interest.
Exposure*	The process by which an agent comes into contact with a person or animal in such a way that the person or animal may develop the relevant outcome, such as a disease. For this review, exposure relates to being in the vicinity of <i>wind turbine</i> emissions.
Flicker	See ' <i>Shadow flicker</i> '.
Flicker frequency	The rate of the light pulse or flash resulting from flicker; flash flicker greater than 3 Hz has the potential to provoke photosensitive seizures.
Flicker-induced seizure	Seizure provoked as a result of being exposed to flicker (usually at a frequency >3 Hz), e.g. <i>wind turbine</i> flicker or strobe lighting.
Frequency (hertz, Hz)	The number of sound waves or cycles passing a given point per second; measured in cycles per second (cps; 1 cps = 1 Hz).
Grey literature	Multiple document types and literature produced by government, academia, business and other organisations; may be produced in electronic and print formats; does not claim to be <i>peer reviewed</i> and is not controlled by commercial publishing (i.e. publishing is not the

primary activity of the producing body).

Health*	1. The World Health Organization (WHO) described it, in 1948 in the preamble to its constitution, as: <i>A state of complete physical, mental, and social well-being and not merely the absence of disease or infirmity.</i> 2. In 1984 a WHO health promotion initiative led to expansion of the original WHO description, which can be abbreviated to: <i>The extent to which an individual or a group is able to realise aspirations and satisfy needs, and to change or cope with the environment. Health is a resource for everyday life, not the objective of living; it is a positive concept, emphasising social and personal resources as well as physical capabilities.</i> 3. A state characterised by anatomical, physiological and psychological integrity; the ability to perform personally valued family, work and community roles; the ability to deal with physical, biological, psychological and social stress; a feeling of wellbeing; and freedom from the risk of disease and untimely death.
Health outcome	A measure of health or loss of health that can assess one or more of the following factors: mortality (i.e. rates of death or survival, years of potential life lost, <i>quality-adjusted life years</i> gained, <i>disability-adjusted life years</i> lost), morbidity (e.g. rates of disease or injury, infertility, disability, chronic pain, functional status, psychiatric disorders), positive measures of health (e.g. measures of wellbeing; physical, social or occupational function), or pregnancy and birth rates.
Ice throw	A hazard resulting from the build-up of ice on <i>wind turbine</i> rotor blade surfaces in cold climates; pieces or sheets of ice may be ‘thrown’ from spinning rotating blades once climatic conditions cause the ice to ‘shed’.
Inaudible sound	Sound that is below the <i>audibility threshold</i>, which is dependent on <i>sound pressure level</i> and <i>frequency</i>.
Infrasound	Sound in the <20 Hz frequency range.
Logistic regression	A type of <i>regression analysis</i> used for predicting the outcome of a categorical or binary dependent variable using one or several independent variables that are measured on continuous or categorical scales.
Low-frequency noise	Sound that falls within the frequency range of 20–200 Hz, although the upper limit can vary.
Masking*	Procedures intended to keep participants in a study from knowing some facts or observations that might bias or influence their actions or decisions regarding the study (syn: blinding).

Mechanical sound	Sound produced from the movement and interaction of physical or mechanical parts; for <i>wind turbines</i> , sound produced by the interaction of electrical and rotational parts such as gear box and generator.
Mechanistic evidence (indirect evidence)	Evidence that a mechanism of action explains how the exposure in question may cause the health outcome of interest; the mechanism for causation may be biological, chemical or mechanical in nature (also see the <i>Modified Bradford Hill Guidelines</i>).
Mesopic vision	Mesopic light levels range from luminances (luminous intensity per unit area of light) of approximately 0.001 to 3 cd m ⁻² . Most night-time outdoor and traffic lighting scenarios are in the mesopic range.
Meta-analysis	A statistical approach to combine the results from multiple studies, with the aim of producing a more precise estimate of the impact of an intervention or exposure on a health (or other) outcome, given that the method increases statistical power. Individual studies contributing to the pooled result may be weighted according to certain criteria, which will vary depending on the meta-analytic method chosen. The analysis can also be used to determine patterns and differences in the impact of an intervention or exposure on a health outcome under different circumstances.
Moderator/mediator*	A variable that occurs in a causal pathway from a causal (independent) variable to an outcome (dependent) variable. It causes variation in the outcome variable and itself is caused to vary by the original causal variable. Such a variable will be associated with both the causal and the outcome variables. Also known as an intermediate, intervening or contingent variable.
Modified Bradford Hill Guidelines	A set of guidelines proposed to determine whether there is a causal relationship between an exposure and an outcome in the absence of experimental evidence, revised from those originally devised by the epidemiologist and statistician Austin Bradford Hill; the Guidelines fall into categories of <i>direct</i> , <i>mechanistic</i> and <i>parallel evidence</i> (see Table 5 for the causality framework for this review).
Morbidity*	- Any departure, subjective or objective, from a state of physiological or psychological wellbeing. In this sense sickness, illness and morbid condition are similarly defined and synonymous. - The WHO Expert Committee on Health Statistics noted in its sixth report (1959) that morbidity could be measured in terms of three units: - persons who were ill - the illnesses (periods or spells of illness) that these persons experienced - the duration (days, weeks etc.) of these illnesses.

Mortality	Death									
Nocebo effect	An unpleasant or adverse effect attributable to administration of or exposure to a <i>placebo</i> ; in this case the placebo may be referred to as a nocebo.									
Noise	Unwanted sound or an unwanted combination of sounds.									
Narrative review	A literature review conducted without a pre-defined protocol or method, including an exhaustive search of the literature, pre-specified criteria for selecting studies and pre-defined approaches to critical appraisal of the internal and external validity of the results obtained. A narrative review is not considered to be transparent, unbiased and reproducible by an independent reviewer.									
Odds ratio (OR)*	The ratio of two odds, i.e. the ratio of the odds (<i>probability/1-probability</i>) of an event occurring in one group to the odds of it occurring in another group. The term ‘odds’ is defined differently according to the situation under discussion. Consider the following notation for the distribution of a binary exposure and a disease in a population or sample: <table><tr><td></td><td>Exposed</td><td>Unexposed</td></tr><tr><td>Disease</td><td>a</td><td>b</td></tr><tr><td>No disease</td><td>c</td><td>d</td></tr></table> The odds ratio (cross-product ratio) is ad/bc.		Exposed	Unexposed	Disease	a	b	No disease	c	d
	Exposed	Unexposed								
Disease	a	b								
No disease	c	d								
Parallel evidence (indirect evidence)	Evidence obtained from related fields that support the association between the exposure of interest and an adverse health effect; evidence may occur in a setting other than that under investigation, and should have replicable results under the same conditions or with similar results under different conditions (also see <i>Modified Bradford Hill Guidelines</i>).									
Participants/responders	Those who have participated in a trial or study, or have responded to a survey questionnaire or interview.									
Pearling	The process of checking the reference lists of articles included in a systematic review for more articles that are potentially relevant.									
Pearson’s correlation coefficient (r)	A coefficient derived with Pearson’s product-moment correlation; the values range from -1.0 to 1.0, with a high value indicating a strong correlation between variables.									
Peer-reviewed literature	Published literature that has undergone evaluation by other people in the same field in order to maintain or enhance the quality of the work or performance in that field; in this review, databases included in the <i>black literature</i> search contain only peer-reviewed literature.									
Photoparoxysmal response	A physiological reaction to intermittent photic stimulation or other visual stimuli of daily life; detected and measured with electroencephalography (EEG).									

Photopic vision	Daylight vision; normal vision in daylight; vision with sufficient illumination that the cones are active and hue can be perceived.
Photosensitivity	An abnormal sensitivity to light stimuli, usually detected with electroencephalography (EEG) as a paroxysmal reaction to intermittent photic stimulation.
Photosensitive epilepsy	A form of epilepsy in which seizures are triggered by visual stimuli that form patterns in time or space, such as flashing lights; bold, regular patterns; flicker; or regular moving patterns.
Physical emission	For <i>wind turbines</i> , recognised physical emissions include <i>noise, infrasound and low-frequency noise, shadow flicker and electromagnetic radiation</i> .
Placebo*	A medication or procedure that is inert (i.e. one having no pharmacological effect) but intended to give patients the perception that they are receiving treatment or assistance for their complaint; from the Latin <i>placebo</i> , 'I shall please'.
Prevalence*	A measure of disease occurrence; the total number of individuals who have an attribute or disease at a particular time (it may be a particular period) divided by the population at risk of having the attribute or disease at that time or midway through the period; when used without qualification, the term usually refers to the situation at a specified point in time (point prevalence); a measure of occurrence or disease frequency, often used to refer to the proportion (not the rate) of individuals in a population who have a disease or condition.
Probability (p)*	A measure, ranging from 0 to 1, of the degree of belief in a hypothesis or statement. All probabilities obey the laws given by the axioms that: - All probabilities (p) are 0 or greater: for any event or statement A, $p(A) \geq 0$ - The probability of anything certain to happen is 1; i.e. if A is certain, $p(A)=1$ - If two events or statements, A and B, cannot both be true at once (i.e. they are mutually exclusive), the probability of their conjunction (A or B) is the sum of their separate probabilities: $p(A \text{ or } B)=p(A)+p(B)$.
P (or p) value*	The probability that a test statistic would be as extreme as observed, or more extreme, if the null hypothesis was true; the letter <i>P</i> (or <i>p</i>) stands for this probability. It is usually close to the probability that the difference observed or greater could have occurred by chance alone, i.e. under the null hypothesis. Investigators may arbitrarily set their own significance levels, but in most biomedical and epidemiological work, a study result whose <i>P</i> (or <i>p</i>) value is less than 5% ($p<0.05$) or 1% ($p<0.01$) is considered sufficiently unlikely to have occurred by chance to justify the designation 'statistically significant'.

Pseudo- R^2	The proportion of the total variability in outcome that is accounted for by the model parameter(s), calculated using various methods; used in <i>logistic regression</i> as an approximation of the R^2 (coefficient of determination) calculated in linear regression—the more variability explained, the better the prediction model.
Publication bias*	1. The result of the tendency of authors to submit, organisations to encourage, reviewers to approve, and editors to publish articles containing “positive” findings (e.g., a gene—disease association), especially “new” results, in contrast to findings or reports that do not report statistically significant or “positive” results. 2. Tendency of authors to preferentially include in their study reports findings that conform to their preconceived notions or outcomes preferred by their institution or sponsor.
Quality of life (QoL)	An individual's perception of their position in life in the context of the culture and value systems in which they live, and in relation to their goals, expectations, standards and concerns. It is a broad-ranging concept affected in a complex way by the person's physical health, psychological state, level of independence and social relationships, and their relationship to salient features of their environment.
Randomisation	A system of allocating individuals to groups with a known (usually equal) chance of being assigned to particular groups. The approach is similar to tossing a coin (e.g. assignment to one group if the coin lands ‘heads’ and to another group if the coin lands ‘tails’); it is often computer generated by an independent third party as this helps avoid <i>bias</i> ; i.e., it reduces intentional or unintentional subverting of randomisation by concealing the allocation.
Randomised controlled trial (RCT)*	An epidemiological experiment in which subjects in a population are randomly allocated into groups, usually called study and control groups, to receive or not receive an experimental preventive or therapeutic procedure, manoeuvre or intervention. The results are assessed by rigorous comparison of rates of disease, death, recovery or other appropriate outcome in the study and control groups. RCTs are generally regarded as the most scientifically rigorous method of hypothesis testing available in epidemiology and medicine. Nonetheless, they may suffer serious lack of generalisability due, for example, to the non-representativeness of patients who are ethically and practically eligible, chosen or consent to participate.
Recall bias*	Systematic error due to differences in accuracy or completeness of recall to memory of past events or experiences. For example, a mother whose child has died of leukemia may be more likely than the mother of a healthy living child to remember details of such past experiences as use of x-ray services when the child was <i>in utero</i> .
Regression analysis	A statistical technique for estimating the ‘best’ mathematical model to describe or predict the dependent variable as a function of the

independent variable(s). There are several regression models that suit different needs, common forms being linear, logistic and proportional hazards.

Relative risk*	The ratio of the risk of an event among the exposed to the risk among the unexposed; this usage is synonymous with risk ratio.
Replication*/replicability	The execution of an experiment or survey more than once so as to confirm the findings, increase precision and obtain a closer estimation of sampling error.
Reversibility	The ability of an effect of an intervention or exposure to be reversed by its removal.
Risk factor*	1. An aspect of personal behaviour or lifestyle, an environmental exposure, or an inborn or inherited characteristic that, on the basis of scientific evidence, is known to be associated with meaningful health-related condition(s). 2. An attribute or exposure that is associated with an increased probability of a specified outcome, such as the occurrence of a disease. Not necessarily a causal factor, it may be a risk marker. 3. A determinant that can be modified by intervention, thereby reducing the probability of occurrence of disease or other outcomes. It may be referred to as a modifiable risk factor, and logically must be a cause of the disease.
Sample selection bias* (sampling bias, see selection bias)	Systematic error due to the methods or procedures used to sample or select the study subjects, specimens, or items (e.g., scientific papers), including errors due to the study of a nonrandom sample of a population.
Selection bias*	1. Bias of the estimated effect of an exposure on an outcome due to conditioning on a common effect of the exposure and the outcome (or of causes of the exposure and the outcome). 2. Distortions that result from procedures used to select subjects and from factors that influence participation in the study. A distortion in the estimate of the effect due to the manner in which subjects are selected for the study. Systematic differences in past exposures and other characteristics between subjects who take part in a study and those who do not may or may not cause selection biases, depending on the study limited to volunteers or to persons present in a particular place at a particular time; studies based on disease survivors; hospital-based studies that cannot include patients who die before hospital admission due to acute illness or that do not include persons with mild conditions, which seldom require hospital care; case-control studies in which selection of cases and controls is differentially influenced by cost, distance, concomitant illnesses, access to diagnostic procedures, or other factors. Selection biases may be

related to confounding and information biases. In clinical trials, two kinds of selection bias are especially relevant: sample selection bias or sampling bias (systematic differences among participants and nonparticipants in trials) and attrition bias (systematic differences due to selective loss of subjects, also known as follow-up bias).

Selection bias can virtually never be corrected by statistical analysis. It is a common and commonly overlooked problem, not just in epidemiological studies but also in clinical and basic biological studies.

Scotopic vision	The vision of the eye under low light conditions.
Shadow flicker	The flickering effect caused when rotating <i>wind turbine</i> blades intermittently cast shadows over neighbouring properties, through constrained openings such as windows, as they turn; <i>exposure</i> is determined by the hub height, blade diameter, height of the sun and blade direction relative to the observer, as well as by environmental factors such as time of day, weather conditions, wind direction, wind speed and geographical location.
Similarity	A description of studies having findings that differ little from each other.
Snowballing	A process of locating, tracking and chasing down references in the footnotes and bibliographies of articles and other documents as part of a continuous process of scanning and collating references.
Socioeconomic status*	A descriptive term for a person's position in society, which may be expressed on an ordinal scale using such criteria as income, level of education attained, occupation, value of dwelling place etc.
Sound	An energy form that travels from a source in the form of waves or pressure fluctuations, transmitted through a medium and received by a receiver (e.g. human ear).
Sound frequency ranges	Infrasound <20 Hz, low-frequency sound 20–200 Hz, mid-frequency sound 200–2000 Hz, high-frequency sound 2000–20,000 Hz.
Sound intensity (I)	A measure of the <i>sound power</i> per unit area of a sound wave; alternatively, the product of the sound pressure and the particle velocity.
Sound power	A measure of the sonic energy per unit of time of a sound wave; alternatively called acoustic power; calculated by the sound intensity times the unit area of the wave; the total acoustic power emitted in all directions by the source.
Sound pressure	A measure of the <i>sound power</i> at a given observer location; can be measured at that specific point by a single microphone or receiver.
Sound pressure level	A logarithmic measure of the <i>sound pressure</i> of a sound relative to a reference value, measured in decibels (dB) above a standard

(SPL)	reference level using the formula $SPL = 10\log_{10}[p^2/p_{ref}^2]$, where p_{ref} is the reference pressure or 'zero' reference for airborne sound (20×10^{-6} pascals).
Spatial proximity	A description of evidence that shows that a health outcome occurs at the same site as the exposure under investigation (see <i>Modified Bradford Hill Guidelines</i>).
Spearman's correlation coefficient (r_s)	A coefficient derived with Spearman's rank-order correlation; the values range from -1.0 to 1.0, with a high value indicating a strong correlation between variables.
Statistical significance*	1. The probability of the observed or larger value of a test statistic under the null hypothesis; often equivalent to the probability of the observed or larger degree of association under the null hypothesis. This usage is synonymous with P (or <i>p</i>) value. 2. A statistical property of an observation or estimate that is unlikely to have occurred by chance alone.
Stress (distress)	A state of mental or emotional strain or tension resulting from adverse or demanding circumstances; distress is a state of extreme anxiety, sorrow or pain.
Systematic literature review	A process by which a body of literature is reviewed and assessed using systematic pre-specified methods that are intended to identify, appraise, select and synthesise high-quality evidence; the methodology is designed to reduce <i>bias</i> in the review process and for findings to be reproducible.
Unspecified noise	Noise for which study authors have not specified a frequency range or decibel level.
Urbanisation	The physical growth of urban areas as a result of rural migration and suburban concentration into cities.
Temporal proximity	A description of evidence that shows that an exposure precedes an effect or health outcome (see <i>Modified Bradford Hill Guidelines</i>).
Tinnitus	The conscious perception of sound in the absence of an external source.
Tonal sound	Sound at discrete frequencies.
Weighted sound pressure level	The results of measuring a sound and applying a filter: A-weighting: the most common scale for assessing environmental and occupational sound. The result is a level measured in dB(A). C-weighting: a filter that does not reduce low frequencies to the same extent as the A-weight filter. The result is a level measured in dB(C).

G-weighting: designed for infrasound. The result is a level measured in dB(G).

Wind farm	A collection of <i>wind turbines</i> , usually defined by geographical location.
Wind power	The conversion of wind energy into a useful form of energy, e.g. using <i>wind turbines</i> to make electrical power, windmills for mechanical power, or wind-powered pumps.
Wind turbine	A device that converts kinetic energy from the wind, also described as converting wind energy into mechanical energy; if the mechanical energy is used to produce electricity, the device may be called a wind turbine or wind power plant.
Wind turbine emissions	Forces emanating from <i>wind turbines</i> that have the potential to affect those in the vicinity, i.e. <i>audible sound, infrasound, electromagnetic radiation</i> and <i>shadow flicker</i> .

Abbreviations

95%CI	Confidence interval of 95%; a range of values within which there is a 95% probability of the true value occurring
ALS	Amyotrophic lateral sclerosis (a form of motor neuron disease)
ANOVA	Analysis of variance
β	Beta coefficient for a variable in multiple linear regression; scale dependent
CNS	Central nervous system
dB(A)	A-weighted sound pressure level (decibels)
dB(C)	C-weighted sound pressure level (decibels)
dB(G)	G-weighted sound pressure level (decibels)
dB(lin)	Unweighted sound pressure level (decibels), also known as linear or flat-weighting and now superseded by Z-weighting
EEG	Electroencephalography; a recording of electrical activity along the scalp by measurement of voltage fluctuations within the neurons of the brain
EMF	Electromagnetic field; can include ELF—low-frequency electromagnetic field, IF—intermediate frequency field, RF—radiofrequency field
EMR	Electromagnetic radiation
EPA	Environment Protection Authority (South Australia)
EPHC	The Environment Protection and Heritage Council of Australia
ESS	Epworth Sleepiness Scale
Exp(b)	The exponential function of the coefficients of the independent variables in a logistic regression, which corresponds to the odds ratio
GHQ	General Health Questionnaire
HRQOL	Health-Related Quality of Life questionnaire
Hz	Hertz; a measure of frequency equivalent to one cycle per second
ILFN	Infrasound and low-frequency noise
L_{eq} (also LA_{eq})	When a noise varies over time, the L_{eq} is the equivalent continuous sound that would contain the same sound energy as the time-varying sound (e.g. L_{eq} = 60 dB). It is common practice to measure noise levels using the A-weighting setting built into all sound-level meters, in which case the term is properly known as LA_{eq} (e.g. LA_{eq} = 60 dB or L_{eq} = 60 dB(A))
L_{max}	The maximum sound power level measured over a specified period
μg	Microgram, equivalent to 10^{-6} grams; a measure of weight
μT	Microtesla; a measure of electromagnetic radiation, $1 \mu\text{T} = 10 \text{ mG}$
mG	Milligauss, $10 \text{ mG} = 1 \mu\text{T}$ (microtesla); a measure of electromagnetic radiation
n	Number of respondents or participants
NHMRC	National Health and Medical Research Council

OR	Odds ratio
pmol/L	Picomoles per litre, equivalent to 10^{-12} mol/L; a chemical measure of concentration
nmol/L	Nanomoles per litre, equivalent to 1000 pmol/L
p	Probability
PPR	Photoparoxysmal response
PRISMA	Preferred Reporting Items for Systematic reviews and Meta-analysis
PSQI	Pittsburgh Sleep Quality Index
QoL	Quality of life
r	Pearson's correlation coefficient
REM sleep	Rapid eye movement sleep
r_s	Spearman's correlation coefficient
SES	Socioeconomic status
SF-36v2	Short Form (36) Health Survey (version 2)—provides a summary Physical Component Score (PCS) and a summary Mental Component Score (MCS)
SPL	Sound pressure level
SWA	Slow wave activity
SWS	Slow wave sleep
$X_{shadow, max}$	The maximum distance from a <i>wind turbine</i> that <i>shadow flicker</i> can extend, which can be estimated by the formula: $X_{shadow, max} = (H+R-h_{view})/\tan(\alpha_s)$ where H = turbine height, R = rotor radius, h_{view} = height of the viewing point, α_s = altitude of the sun (Ellenbogen et al. 2012)

APPENDIX A – SEARCH STRATEGIES

Grey literature sources

Wind turbine*; wind farm*; wind power; wind turbine syndrome

Limits: 1981 – 10/2012; English language; human studies

Source	Location	Search terms
Google Scholar	http://scholar.google.com.au/	Health AND human AND ("wind farm" OR "wind tower" OR "wind turbine" OR "wind power" OR "wind technology" OR "wind energy") Limits: the first 200 citations will be assessed
PapersFirst database (database of papers presented at conferences)	University Library (‘databases’ search)	(health) AND ("wind turbin*" OR "wind tower*" OR "wind farm*" OR "wind power*" OR "wind renewable energy" OR "wind power plant*" OR "wind technolog*" OR "wind energy" OR "wind resourc*") Limits: English language, published 1981 - 2012
ProceedingsFirst database (database of conference proceedings)	University Library (‘databases’ search)	(health) AND ("wind turbin*" OR "wind tower*" OR "wind farm*" OR "wind power*" OR "wind renewable energy" OR "wind power plant*" OR "wind technolog*" OR "wind energy" OR "wind resourc*") Limits: English language, published 2011 - 2012
EPPI Centre (papers on public policy) Evidence library Bibliomap database DoPHER database TroPHI database	http://eppi.ioe.ac.uk/cms/	"wind" (free text search)
Scirus (documents from science/scientist webpages) Restricted to ‘Other web’ sources to avoid duplicating black literature sources	http://www.scirus.com/	Wind turbine*" OR "wind farm*" OR "wind power" OR "renewable energy" OR "power plant*" OR "wind turbine syndrome" OR "energy generating resources" OR "wind tower*" OR "wind

		energy" OR "wind technology" AND "health" AND "health effects" AND "adverse health effects" AND "adverse health effects" AND "human*"
WHOLIS (World Health Organization technical documents)	http://www.who.int/ library/databases/en/ /	'wind' (words or phrase search)
TROVE (National Library of Australia resources)	http://trove.nla.gov. au/	"wind farm" "wind power" "wind tower" "wind turbine" "wind technology" "wind energy" "wind" AND "renewable energy" "wind resources"
WorldCat (network of library content)	http://www.worldc at.org/	("wind turbine" OR "wind tower" OR "wind farm" OR "wind power" OR "wind renewable energy" OR "wind power plant" OR "wind technology" OR "wind energy" OR "wind resource") AND (noise OR flicker OR "electromagnetic radiation" OR health) Limits: key word search, English, 1981 – 2012, articles
OpenDOAR (directory of open access repositories)	http://www.opend oar.org/search.php	("wind farms" OR "wind turbines" OR "wind towers" OR "wind power") AND human AND (health OR flicker OR noise OR electromagnetic) The first 50 citations will be assessed
MedNar Restricted to World Health Organization, US Department of Health and Human Services, National Center for Health Statistics	www.mednar.com	Keyword: ("wind farms" OR "wind turbines" OR "wind towers" OR "wind power") AND (health OR flicker OR human OR noise OR electromagnetic)

APPENDIX B – EVIDENCE TABLES FOR INCLUDED ARTICLES

Evidence map—11 articles relating to 7 studies

Study identifier	Most comprehensive report	Study location	Articles contributing additional data on the study and/or providing additional analyses or comparisons between studies
NL-07	Bakker et al. (2012)	The Netherlands	Van den Berg et al. (2008) Pedersen et al. (2009) Pedersen (2011)
Krogh et al. (2011)	Krogh et al. (2011)	Ontario, Canada	
Morris (2012)	Morris (2012)	South Australia	
Nissenbaum, Aramini and Hanning (2012)	Nissenbaum, Aramini and Hanning (2012)	Maine, USA	
SWE-00	Pedersen and Persson Waye (2004)	Sweden	Pedersen and Larsman (2008) Pedersen (2011)
SWE-05	Pedersen and Persson Waye (2007)	Sweden	Pedersen and Larsman (2008) Pedersen (2011)
Shepherd et al. (2011)	Shepherd et al. (2011)	New Zealand	

Included articles – citation details

Bakker, RH, Pedersen, E, van den Berg, GP, Stewart, RE, Lok, W & Bouma, J 2012, 'Impact of wind turbine sound on annoyance, self-reported sleep disturbance and psychological distress', *Science of the Total Environment*, vol. 425, pp. 42–51.

Krogh, CME, Gillis, L, Kouwen, N & Aramini, J 2011, 'WindVOiCe, a self-reporting survey: adverse health effects, industrial wind turbines, and the need for vigilance monitoring', *Bulletin of Science, Technology & Society*, vol. 31, no. 4, pp. 334–345.

Morris, M 2012, 'Waterloo wind farm survey', Electronic self-published report, Accessed 18 January 2013, <www.wind-watch.org/news/wp-content/uploads/2012/07/Waterloo-Wind-Farm-Survey-April-2012-Select-Committee.pdf>.

Nissenbaum M, Aramini J & Hanning C 2012, 'Effects of industrial wind turbine noise on sleep and health', *Noise & Health*, vol. 14, no. 60, pp. 237–243.

Pedersen, E 2011, 'Health aspects associated with wind turbine noise: results from three field studies', *Noise Control Engineering Journal*, vol. 59, no. 1, pp. 47–53.

Pedersen, E & Larsman, P 2008, 'The impact of visual factors on noise annoyance among people living in the vicinity of wind turbines', *Journal of Environmental Psychology*, vol. 28, no. 4, pp. 379–389.

Pedersen, E & Persson Waye, K 2004, 'Perception and annoyance due to wind turbine noise: a dose-response relationship', *Journal of the Acoustical Society of America*, vol. 116, no. 6, pp. 3460–3470.

Pedersen, E & Persson Waye, K 2007, 'Wind turbine noise, annoyance and self-reported health and well-being in different living environments', *Occupational and Environmental Medicine*, vol. 64, no. 7, pp. 480–486.

Pedersen, E, van den Berg, F, Bakker, R & Bouma, J 2009, 'Response to noise from modern wind farms in The Netherlands', *Journal of the Acoustical Society of America*, vol. 126, p. 634.

Shepherd, D, McBride, D, Welch, D, Dirks, KN & Hill, EM 2011, 'Evaluating the impact of wind turbine noise on health-related quality of life', *Noise & Health*, vol. 13, no. 54, pp. 333–339.

Van den Berg, G, Pedersen, E, Bouma, J & Bakker, R 2008, *Project WINDFARM perception: Visual and acoustic impact of wind turbine farms on residents*, 2012/11/13/06:24:13, University of Groningen, FP6-2005-Science-and-Society-20, Specific Support Action, Project no. 044628, viewed 13 November 2012, <<http://www.epaw.org/documents/WFp-final-summary-1.pdf>>.

ARTICLE DETAILS		
Reference [1] Bakker , RH, Pedersen, E, van den Berg, GP, Stewart, RE, Lok, W & Bouma, J 2012 , 'Impact of wind turbine sound on annoyance, self-reported sleep disturbance and psychological distress', <i>Science of the Total Environment</i> , vol. 425, pp. 42–51.		
Affiliation/source of funds [2] Department of Applied Research in Care, University Medical Center Groningen, University of Groningen, The Netherlands; Halmstad University and Environmental Psychology, Department of Architecture and Built Environment, Lund University, Halmstad, Sweden; GGD Amsterdam Public Health Service, Amsterdam, The Netherlands; Department of Community and Occupational Health, University Medical Center Groningen, University of Groningen, The Netherlands; Department of Health Care, Science shop, University Medical Center Groningen, University of Groningen, The Netherlands. No external funding for the study was declared; however, this study is a selected analysis of an earlier publication detailing research funded by the European Union.		
Study design [3] Cross-sectional study—see van den Berg, G, Pedersen, E, Bouma, J & Bakker, R 2008, <i>Project WINDFARM perception: visual and acoustic impact of wind turbine farms on residents</i>, University of Groningen, FP6-2005-Science-and-Society-20, Specific Support Action, Project no. 044628.	Level of evidence [4] IV	Location/setting [5] Rural and urban settings in The Netherlands with flat topography; rural environments were classified according to whether or not a major road was located within 500 m of the closest wind turbine. Proximity/distance: Study population sampled from addresses within 2.5 km of a wind turbine, with a second turbine <500 m from the first turbine.
Exposure description [6] Wind farm details: Two or more turbines within 2.5 km of any given residence surveyed; the two closest turbines were required to have nominal electric power ≥ 500 kW. Additional turbines within 2.5 km of residence were included in analysis regardless of power output. Specific exposure details: Modelled sound pressure in A-weighted decibels (dB(A))^a outside residences averaged over time with 8 m/s downwind; range = 21–54 dB(A), mean = 35 dB(A).	Control(s) description [8] No non-exposed groups were included in the study. Study population was divided into categories of estimated SPL (see 'Specific exposure details' and 'Population characteristics'). Sample size [9] See 'Population characteristics'. Survey sample selected from addresses provided by Land Registry Office – for each subgroup either a random sample was selected or all addresses that	

Frequency range of sound not reported, i.e. exposure profile in terms of audible noise versus infrasound not analysed. ^a Sound power levels collected from reports by consultancies, manufacturers and local authorities; or, where data were unavailable (older/smaller machines), the sound power level of a turbine with the same dimensions and electrical output was used; propagation of sound from turbines was calculated in accordance with the ISO standard model (see ISO 1996, 'Attenuation of sound during propagation outdoors. Part 2: General method of calculation', ISO 9613-2, International Organization for Standardization, Geneva). Sample size [7] Total, n=1948; respondents, n=725; non-respondents, n=1223; response rate 37%.	matched postcodes within 2.5 km of selected wind turbines. Subgroups were: rural area, rural area with a major road, densely populated built-up area.																																																																					
Population characteristics [10] As per van den Berg et al. (2008) and Bakker et al. (2012). <table><tr><th rowspan="2"></th><th colspan="6">Sound pressure level, in dB(A)</th></tr><tr><th><30</th><th>30–35</th><th>36–40</th><th>41–45</th><th>>45</th><th>Total</th></tr><tr><td>Study sample, n</td><td>491</td><td>589</td><td>421</td><td>250</td><td>197</td><td>1948</td></tr><tr><td>Respondents, n (%)</td><td></td><td></td><td></td><td></td><td></td><td></td></tr><tr><td>Built-up area</td><td>68 (37)</td><td>84 (38)</td><td>28 (17)</td><td>18 (19)</td><td>1 (2)</td><td>199 (23)</td></tr><tr><td>Rural with main road</td><td>50 (27)</td><td>70 (32)</td><td>59 (38)</td><td>36 (38)</td><td>30 (46)</td><td>245 (36)</td></tr><tr><td>Rural without main road</td><td>67 (36)</td><td>65 (30)</td><td>75 (47)</td><td>40 (43)</td><td>34 (52)</td><td>281 (41)</td></tr><tr><td>Total</td><td>185 (38)</td><td>219 (37)</td><td>162 (38)</td><td>94 (38)</td><td>65 (33)</td><td>725 (100)</td></tr><tr><td>Age, mean (years)</td><td>NR</td><td>NR</td><td>NR</td><td>NR</td><td>NR</td><td>51</td></tr><tr><td>Sex, % male</td><td>NR</td><td>NR</td><td>NR</td><td>NR</td><td>NR</td><td>51</td></tr></table>			Sound pressure level, in dB(A)						<30	30–35	36–40	41–45	>45	Total	Study sample, n	491	589	421	250	197	1948	Respondents, n (%)							Built-up area	68 (37)	84 (38)	28 (17)	18 (19)	1 (2)	199 (23)	Rural with main road	50 (27)	70 (32)	59 (38)	36 (38)	30 (46)	245 (36)	Rural without main road	67 (36)	65 (30)	75 (47)	40 (43)	34 (52)	281 (41)	Total	185 (38)	219 (37)	162 (38)	94 (38)	65 (33)	725 (100)	Age, mean (years)	NR	NR	NR	NR	NR	51	Sex, % male	NR	NR	NR	NR	NR	51
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Length of follow-up [11] NA (cross-sectional study design).	Outcome(s) measured and/or analyses undertaken [12] Author-developed survey measuring response (sleep disturbance, psychological stress, annoyance) to wind turbine sound outdoors and indoors, overall, and those who did and did not benefit economically from wind turbines. Correlations between sound exposure and: • sleep disturbance • psychological distress scores as determined by General Health Questionnaire (GHQ-12) <i>[validated]</i> • annoyance outside • annoyance inside. Correlations between variables were considered across																																																																					

	different environments in terms of background noise ('noisy' and 'quiet') and across different response groups ('do notice wind turbine noise' and 'do not notice wind turbine noise').
INTERNAL VALIDITY Confounding subscale [13] <i>Comment on sources of confounding:</i> Few details on characteristics of participants were reported. Adjustments made for influence of age, gender, employment, terrain, urbanisation, economic benefit from turbines, background noise, noise sensitivity, attitude to turbines and turbine visibility. Findings may be partly explained by differences in levels of background sound between rural and urban areas. Covariates varied between the analyses. Plausible confounders that were not addressed included socioeconomic factors, chronic disease and risk factors for chronic disease and occupation. Bias subscale [14] <i>Comment on sources of bias:</i> High potential for sample selection bias due to low response rate. It is uncertain whether participants were effectively masked regarding the purpose of the survey (and thus the impact of recall bias is uncertain) – questions about other environmental factors were added to obtain better masking of the main topic. Equal weight was given to questions regarding other environmental factors but it is unclear whether study intent was known, leading to the possibility of responder bias (conscious or unconscious). Non-responder analysis conducted but only on 95 of the 200 randomly selected non-responders (non-responders=1223), so it is may not be representative.	EXTERNAL VALIDITY Generalisability [15] Survey mailed to a sample of households within 2.5 km of wind turbines; potential for differences between the total population living near the included wind farms and those that responded to the questionnaire. Applicability [16] Unknown whether the population characteristics and the wind turbine exposures of those living near wind farms in The Netherlands are comparable to those living near wind farms in Australia.
Reporting subscale [17] <i>Comment on quality of reporting:</i> Main deficits include lack of reporting on distribution of participant characteristics across the nominated and estimated sound exposure levels (only an overall measure for mean age and sex) and limited demographic information on non-responders.	
Chance [18] This paper by Bakker et al. presents additional analyses of earlier work, led by van den Berg (see below). Bakker et al. present numerous statistical tests for correlations based on structural equation modelling. No adjustments	

were made for multiple comparisons. The possibility of spurious significant associations arising by chance cannot be excluded.

Overall quality assessment (descriptive) [19]

On the basis of the Internal Validity assessment made above, and the detailed critical appraisal of the study given in Table 7, this study is considered poor quality for the purpose of this review.

There was some adjustment for potential confounding, although some plausible confounders were not addressed. There is potential for recall bias and outcome misclassification due, respectively, to uncertainty in the effectiveness of masked study intent and dependence on self-report in a questionnaire that has not been formally validated. There is a high risk of exposure misclassification (time and person criteria not well-defined), sample selection bias (37% response rate) and statistically significant associations occurring due to chance (multiple statistical tests and no correction for multiple comparisons).

RESULTS

Adverse effect outcomes [20]

<i>Response to wind turbine sound, outdoors and indoors</i>						
	Do not notice, n (%)	Notice, not annoyed, n (%)	Slightly annoyed, n (%)	Rather annoyed, n (%)	Very annoyed, n (%)	Total, n (%)
Sound outdoors	284 (40)	259 (37)	92 (13)	44 (6)	29 (4)	708 (100)
Sound indoors	465 (67)	139 (20)	54 (8)	21 (3)	20 (3)	699 (100)
<i>Response to outdoor wind turbine among economically benefiting and non-benefiting respondents</i>						
	Do not notice, n (%)	Notice, not annoyed, n (%)	Slightly annoyed, n (%)	Rather annoyed, n (%)	Very annoyed, n (%)	Total, n (%)
Benefit	255 (44)	184 (31)	78 (13)	41 (7)	28 (5)	586 (100)
No benefit	15 (15)	68 (69)	13 (13)	2 (2)	1 (1)	99 (100)
<i>Response to indoor wind turbine among economically benefiting and non-benefiting respondents</i>						
	Do not notice, n (%)	Notice, not annoyed, n (%)	Slightly annoyed, n (%)	Rather annoyed, n (%)	Very annoyed, n (%)	Total, n (%)
Benefit	394 (68)	98 (17)	46 (8)	21 (4)	20 (4)	579 (100)
No benefit	53 (54)	39 (39)	7 (7)	0 (0)	0 (0)	99 (100)
<i>Response to wind turbine sound outdoors in relation to 5-dB(A) intervals of sound (respondents with economic benefit only)</i>						
	<30 n (%)	30–35 n (%)	36–40 n (%)	41–45 n (%)	>45 n (%)	Total n (%)
Do not notice	124 (75)	92 (46)	30 (21)	7 (12)	2 (10)	255 (44)
Notice, not annoyed	34 (21)	71 (36)	52 (37)	22 (37)	5 (24)	184 (31)
Slightly annoyed	4 (2)	20 (10)	30 (21)	16 (27)	8 (38)	78 (13)
Rather annoyed	2 (1)	13 (7)	19 (14)	4 (7)	3 (14)	41 (7)
Very annoyed	2 (1)	3 (2)	9 (6)	11 (18)	3 (14)	28 (5)
Total	166 (100)	199 (100)	140 (100)	60 (100)	21 (100)	586 (100)
<i>Response to wind turbine sound indoors in relation to 5-dB(A) intervals of sound (respondents without economic benefit only)</i>						
	<30 n (%)	30–35 n (%)	36–40 n (%)	41–45 n (%)	>45 n (%)	Total n (%)
Do not notice	144 (86)	140 (73)	85 (61)	18 (30)	7 (33)	394 (68)
Notice, not annoyed	19 (11)	27 (14)	29 (21)	15 (25)	8 (38)	98 (17)
Slightly annoyed	2 (1)	16 (8)	14 (10)	12 (20)	2 (10)	46 (8)

Rather annoyed	0	(0)	6	(3)	6	(4)	6	(10)	3	(14)	21	(4)
Very annoyed	2	(1)	2	(1)	6	(4)	9	(15)	1	(5)	20	(4)
Total	167	(100)	191	(100)	140	(100)	60	(100)	21	(100)	579	(100)
Sound sources of sleep disturbance in rural and urban area types												
			Rural n (%)				Urban n (%)				Total n (%)	
Not disturbed			196	(69.8)			288	(64.9)			484	(66.8)
Disturbed by people/animals			33	(11.7)			64	(14.4)			97	(13.4)
Disturbed by traffic/mechanical sounds			35	(12.5)			75	(16.9)			110	(15.2)
Disturbed by wind turbines			17	(6.0)			17	(3.8)			34	(4.7)
Total			281	(100)			444	(100)			725	(100)
Correlation matrices												
			Sleep disturbance				Psychological distress				Age	
Quiet + noisy, do not notice turbine sound (n=323)												
Sleep disturbance			NA				NR				NR	
Psychological distress			0.191**				NA				NR	
Age			0.172**				-0.129*				NA	
Sound exposure			0.005				0.053				-0.068	
			Annoyance outside	Annoyance inside			Sleep disturbance		Psychological distress		Age	
Quiet + noisy, do not notice turbine sound (n=323)												
Annoyance outside			NA	NR			NR		NR		NR	
Annoyance inside			0.78 ^a	NA			NR		NR		NR	
Sleep disturbance			0.444 ^a	0.493 ^a			NA		NR		NR	
Psychological distress			0.184 ^a	0.243 ^a			0.205 ^a		NA		NR	
Age			0.116	0.084			0.071		-0.77		NA	
Sound exposure			0.281 ^a	0.206 ^a			0.094		0.160 ^a		-0.084	
			Annoyance outside	Annoyance inside			Sleep disturbance		Psychological distress		Age	
Noisy, do notice turbine sound (n=147)												
Annoyance outside			NA	NR			NR		NR		NR	
Annoyance inside			0.782 ^a	NA			NR		NR		NR	
Sleep disturbance			0.499 ^a	0.534 ^a			NA		NR		NR	
Psychological distress			0.174 ^b	0.217 ^a			0.220 ^a		NA		NR	
Age			0.236 ^a	0.157			0.084		-0.87		NA	
Sound exposure			0.057	0.065			0.014		0.13		-0.146	
			Annoyance outside	Annoyance inside			Sleep disturbance		Psychological distress		Age	
Quiet, do notice turbine sound (n=118)												
Annoyance outside			NA	NR			NR		NR		NR	
Annoyance inside			0.783 ^a	NA			NR		NR		NR	
Sleep disturbance			0.380 ^a	0.438 ^a			NA		NR		NR	
Psychological distress			0.201 ^b	0.282 ^a			0.182 ^b		NA		NR	
Age			-0.027	-0.012			0.045		-0.65		NA	
Sound exposure			0.533	0.382 ^a			0.200 ^b		0.208 ^b		0.007	
^a p<0.01												
^b p<0.05												

Exposure group [21] See 'Adverse effect outcomes' [20].	Control group [22] NA	Measure of effect / effect size [23] 95% CI [25] See [20].	Harms (NNH) [24] 95% CI [25] See [20].
Public health importance (1–4) [26] Unable to determine according to NHMRC ranking criteria.		Relevance (1–5) [27] 5	
Comments [28] This study was cross-sectional in design. This does not permit any conclusions regarding causation between health outcomes and noise exposure from turbines; that is, it is unknown whether the self-reported health outcomes occurred prior to or after exposure. Annoyance was considered, but it is not a health outcome and it is uncertain whether it is associated with stress which may be a mediating variable for health. The study has limited capacity to inform the assessment of wind turbine noise as a cause of adverse health effects.			
ARTICLE DETAILS		Study NL-07	
Reference [1] Pedersen , E, van den Berg, F, Bakker, R & Bouma, J 2009 , 'Response to noise from modern wind farms in The Netherlands', <i>Journal of the Acoustical Society of America</i> , vol. 126, no. 2, pp. 634–643.			
Affiliation/source of funds [2] Halmstad University and University of Gothenburg, Halmstad, Sweden; University of Groningen and GGD Amsterdam, The Netherlands; University Medical Centre Groningen, University of Groningen, Groningen, The Netherlands. Funded through the European Union as a Specific Support Action, Contract No. 0044628.			
Study design [3] Cross-sectional study.	Level of evidence [4] IV	Location/setting [5] Areas in The Netherlands with ≥ 2 wind turbines of power ≥ 500 kW. Proximity/distance: Study population sampled from addresses within 2.5 km of a wind turbine with a second turbine < 500 m from the first turbine.	
Exposure description [6] Wind farm details: ≥ 2 wind turbines of power ≥ 500 kW. Specific exposure details: A-weighted sound power levels (dB(A)) in octave bands at 8 m/s wind speed at 10 m height in a neutral atmosphere for all wind turbines were obtained from		Control(s) description [8] No non-exposed groups were included in the study. A distribution of participant characteristics (incomplete) across different sound level exposures was included (see 'Specific exposure details'). Sample size [9]	

consultancies, manufacturers and local authorities; or, where data were unavailable (older/smaller machines), the sound power level of a turbine with the same dimensions and electrical output was used; propagation of sound from turbines was calculated in accordance with the ISO standard model (see ISO 1996, 'Attenuation of sound during propagation outdoors. Part 2: General method of calculation', ISO 9613-2, International Organization for Standardization, Geneva). Sample size [7] Respondents, n=725; non-respondents, n=1223; response rate 37%.	See 'Population characteristics'. Survey sample selected from addresses provided by Land Registry Office – for each subgroup either a random sample was selected or all addresses that matched postcodes within 2.5 km of selected wind turbines. Subgroups were: rural area, rural area with a major road, densely populated built-up area.																																			
Population characteristics [10] Exposure group: <table><tr><th colspan="7">Estimated A-weighted sound pressure intervals in dB(A)^a</th></tr><tr><th></th><th><30</th><th>30–35</th><th>35–40</th><th>40–45</th><th>>45</th><th>Total</th></tr><tr><td>Sample, n</td><td>473</td><td>494</td><td>502</td><td>282</td><td>197</td><td>1948</td></tr><tr><td>Respondents, n</td><td>185</td><td>219</td><td>162</td><td>94</td><td>65</td><td>725</td></tr><tr><td>Response rate, %</td><td>39</td><td>44</td><td>32</td><td>33</td><td>33</td><td>37</td></tr></table> ^a These are the intervals as reported by the authors. Note that the intervals are not mutually exclusive, which limits conclusions based on analysis of different categories of sound pressure exposure. For further details regarding the utility/relevance of results included in this paper, see 'Outcomes measured'.		Estimated A-weighted sound pressure intervals in dB(A) ^a								<30	30–35	35–40	40–45	>45	Total	Sample, n	473	494	502	282	197	1948	Respondents, n	185	219	162	94	65	725	Response rate, %	39	44	32	33	33	37
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Length of follow-up [11] NA (cross-sectional study)	Outcome(s) measured and/or analyses undertaken [12] Results analysed according to five wind turbine estimated noise exposure categories in 5-dB(A) intervals; however, clinical importance of endpoints chosen for this study is difficult to determine ie annoyance is not a health effect. Outcomes measured were: Response (do not notice / annoyance) to wind turbine noise outdoors and indoors, and attitude to wind turbines.																																			
INTERNAL VALIDITY Confounding subscale [13] Comment on sources of confounding: Adjustments made for area type (rural/urban), terrain (e.g. built up/main road), economic benefit from turbines, turbine visibility, background noise, noise sensitivity, attitude to turbines. Covariates varied	EXTERNAL VALIDITY Generalisability [15] Survey of households within 2.5 km of wind turbines; potential for differences between the total population living near the included wind farms and those that responded to questionnaire.																																			

between the analyses. Plausible confounders that were not addressed included socioeconomic status, age, gender, chronic disease and risk factors for chronic disease, occupation, education and employment. Bias subscale [14] Comment on sources of bias: Sample selection bias is more likely with response rates below 70%. Response rate in this study was 37%. Masking of study intent was attempted to reduce recall bias—unclear if successful. Non-responder analysis conducted but no details on ‘responding non-responder’ characteristics.	Applicability [16] Unknown whether the population characteristics and the wind turbine exposures of those living near wind farms in The Netherlands are comparable to those living near wind farms in Australia.																																																						
Reporting subscale [17] Comment on quality of reporting: Inadequate reporting on distribution of participant characteristics across the nominated estimated sound exposure levels (only an overall measure for mean age and sex) and did not provide any demographic information on non-responders.																																																							
Chance [18] Statistical testing focused on prediction of annoyance. Multiple tests undertaken. There was the possibility of spurious significant associations because of the multiple statistical analyses undertaken.																																																							
Overall quality assessment (descriptive) [19] On the basis of the Internal Validity assessment made above, and the detailed critical appraisal of the study given in Table 7, this study is considered poor quality for the purpose of this review. There was some adjustment for potential confounding, although some plausible confounders were not addressed. There is potential for recall bias and outcome misclassification due to uncertainty in the effectiveness of masked study intent and inclusion of non-standard survey questions, respectively. There is a high risk of exposure misclassification (time and person criteria not well-defined) and statistically significant associations occurring due to chance (multiple statistical tests and no Bonferroni correction).																																																							
RESULTS																																																							
Adverse effect outcomes [20] <i>Response to wind turbine noise outdoors or indoors, proportion of respondents (n=708) according to 5-dB(A) sound level intervals.</i> <table><tr><td></td><td colspan="5">Predicted A-weighted sound pressure levels, dB(A)^a</td></tr><tr><td></td><td><30</td><td>30–35</td><td>35–40</td><td>40–45</td><td>>45</td></tr><tr><td>Outdoors, n</td><td>178</td><td>213</td><td>159</td><td>93</td><td>65</td></tr><tr><td> Do not notice</td><td>75 [68,81]</td><td>46 [40,53]</td><td>21 [16,28]</td><td>13 [8,21]</td><td>8 [3,17]</td></tr><tr><td> Notice, not annoyed</td><td>20 [15,27]</td><td>36 [30,43]</td><td>41 [34,49]</td><td>46 [36,56]</td><td>58 [46,70]</td></tr><tr><td> Slightly annoyed</td><td>2 [1,6]</td><td>10 [7,15]</td><td>20 [15,27]</td><td>23 [15,32]</td><td>22 [13,33]</td></tr><tr><td> Rather annoyed</td><td>1 [0,4]</td><td>6 [4,10]</td><td>12 [8,18]</td><td>6 [3,13]</td><td>6 [2,15]</td></tr><tr><td> Very annoyed</td><td>1 [0,4]</td><td>1 [0,4]</td><td>6 [3,10]</td><td>12 [7,20]</td><td>6 [2,15]</td></tr><tr><td>Indoors, n</td><td>178</td><td>203</td><td>159</td><td>93</td><td>65</td></tr></table>			Predicted A-weighted sound pressure levels, dB(A) ^a						<30	30–35	35–40	40–45	>45	Outdoors, n	178	213	159	93	65	Do not notice	75 [68,81]	46 [40,53]	21 [16,28]	13 [8,21]	8 [3,17]	Notice, not annoyed	20 [15,27]	36 [30,43]	41 [34,49]	46 [36,56]	58 [46,70]	Slightly annoyed	2 [1,6]	10 [7,15]	20 [15,27]	23 [15,32]	22 [13,33]	Rather annoyed	1 [0,4]	6 [4,10]	12 [8,18]	6 [3,13]	6 [2,15]	Very annoyed	1 [0,4]	1 [0,4]	6 [3,10]	12 [7,20]	6 [2,15]	Indoors, n	178	203	159	93	65
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Do not notice	87 [81,91]	73 [67,79]	61 [53,68]	37 [28,47]	46 [35,58]
Notice, not annoyed	11 [7,17]	15 [11,20]	22 [16,29]	31 [22,31]	38 [28,51]
Slightly annoyed	1 [0,4]	8 [5,12]	9 [6,15]	16 [10,25]	9 [4,19]
Rather annoyed	0 [0,2]	3 [1,6]	4 [2,8]	6 [3,13]	5 [2,13]
Very annoyed	1 [0,4]	1 [0,4]	4 [2,8]	10 [5,17]	2 [0,8]

Values are % [95% CI] unless otherwise specified.

^a These are the intervals as reported by the authors. Note that the intervals are not mutually exclusive.

Distributions of possible confounding factors in relation to 5-dB(A) sound level intervals, proportion of respondents (n=725) per sound level interval

Predicted A-weighted sound pressure levels, dB(A)^a

	<30 n=185	30–35 n=219	35–40 n=162	40–45 n=94	>45 n=65
Economic benefits, %	2	3	10	34	67
Situational parameters, %					
Wind turbines visible	35	60	90	89	100
Rural area	36	30	46	43	52
Rural area with main road	27	32	36	38	46
Built-up area	37	38	17	19	2
Subjective variables, % [95% CI]					
Noise sensitive	36 [29,43]	25 [19,31]	31 [24,38]	31 [22,41]	23 [15,35]
Negative attitude to turbines	10 [7,16]	14 [10,19]	19 [13,25]	17 [11,26]	9 [4,19]
Negative visual attitude	33 [26,40]	36 [30,43]	45 [37,52]	39 [30,49]	20 [12,41]

Values are % [95% CI] unless otherwise specified.

^a These are the intervals as reported by the authors. Note that the intervals are not mutually exclusive.

Results of logistic regression models using response variables 'do not notice/notice' and 'not annoyed/annoyed' (exposure variable 'sound pressure level' and situational factors were used as independent variables, n=680)

	Estimate (B) ^a	SE ^b	p value	Exp(b) ^c
<u>Do not notice vs notice</u>				
(H-L) ^d (p=0.721)				
Sound pressure level, dB(A)	0.17	0.022	<0.001	1.2
Economic benefit (no/yes)	−0.04	0.376	0.911	1.0
Visibility (no/yes)	1.40	0.214	<0.001	4.1
Area type (reference: rural)				
Rural with main road	−0.74	0.231	<0.01	0.5
Built-up	−0.18	0.240	0.451	0.8
<u>Not annoyed vs annoyed</u>				
(H-L) ^d (p=0.199)				
Sound pressure level, dB(A)	0.13	0.027	<0.001	1.1
Economic benefit (no/yes)	−2.77	0.665	<0.001	0.1
Visibility (no/yes)	2.62	0.740	<0.001	13.7
Area type (reference: rural)				
Rural with main road	−1.07	0.372	<0.01	0.3
Built-up	0.65	0.321	<0.05	1.9

^a Coefficients of the independent variables in the logistic regression.

^b Standard errors of the coefficients.

^c The exponential function of the coefficients of the independent variables in the logistic regression, which corresponds to the odds ratio.

^d Hosmer-Lemeshow goodness-of-fit test; p value >0.05 indicates that there is no statistically significant difference between the modelled and observed data.

Correlations between sound pressure levels, response (5-point scale from 'do not notice' to 'very annoyed') and subjective variables^a

	1	2	3	4
1. Sound pressure level, dB(A)	NA	NR	NR	NR
2. Response (5-point scale)	0.51 ^b	NA	NR	NR
3. Noise sensitivity (5-point scale)	-0.01	0.14 ^b	NA	NR
4. General attitude (5-point scale)	-0.03	0.24 ^b	0.14 ^b	NA
5. Visual attitude (5-point scale)	-0.01	0.29 ^b	0.26 ^b	0.65 ^b

^a Spearman's rank correlation test

^b p<0.001

Abbreviations: NA = not applicable; NR = not reported

Results of logistic regression model with response variables 'not annoyed/annoyed', the exposure variable 'sound pressure level' and individual factors as independent variables (n=670)

	Estimate (B) ^a	SE ^b	p value	Exp(b) ^c
Not annoyed vs annoyed				
(H-L)^d (p=0.977)				
Sound pressure level, dB(A)	0.10	0.025	<0.001	1.1
Noise sensitivity (5-point scale)	0.35	0.138	<0.05	1.4
General attitude (5-point scale)	0.54	0.172	<0.01	1.7
Visual attitude (5-point scale)	1.04	0.215	<0.001	2.8

^a Coefficients of the independent variables in the logistic regression.

^b Standard errors of the coefficients.

^c The exponential function of the coefficients of the independent variables in the logistic regression, which corresponds to the odds ratio.

^d Hosmer-Lemeshow goodness-of-fit test; p value >0.05 indicates that there is no statistically significant difference between the modelled and observed data.

Exposure group [21] See 'Adverse effect outcomes' [20].	Control group [22] NA	Measure of effect / effect size [23] 95% CI [25] See 'Adverse effect outcomes' [20].	Harms (NNH) [24] 95% CI [25] See [20]—although no health effects reported.
Public health importance (1–4) [26] Unable to determine as per NHMRC criteria.		Relevance (1–5) [27] 5	
Comments [28] This study was cross-sectional in design. Annoyance was considered, but it is not a health outcome and it is uncertain whether it is associated with stress which may be a mediating variable for health. The study has limited capacity to inform the assessment of wind turbine noise as a cause of adverse health effects.			

ARTICLE DETAILS		Study NL-07
Reference [1] Van den Berg , G, Pedersen, E, Bouma, J & Bakker, R 2008 , <i>Project WINDFARM perception: visual and acoustic impact of wind turbine farms on residents</i> , University of Groningen, FP6-2005-Science-and-Society-20, Specific Support Action, Project no. 044628.		
Affiliation/source of funds [2] Faculty of Mathematics and Natural Sciences, University of Groningen; Department of Public Health and Community Medicine, Göteborg University; Science Shop for Medicine and Public Health, University Medical Centre Groningen; Northern Centre for Health Care Research, University Medical Centre Groningen. Funded by the European Union.		
Study design [3] Cross-sectional study.	Level of evidence [4] IV	Location/setting [5] Rural and urban settings in The Netherlands with flat topography; rural environments were classified according to whether or not a major road was located within 500 m of the closest wind turbine. Proximity/distance: Study population sampled from addresses within 2.5 km of a wind turbine with a second turbine <500 m from the first turbine.
Exposure description [6] Wind farm details: Turbine number within proximity of any given residence surveyed, $n \geq 2$; the two closest turbines were required to have nominal electric power ≥ 500 kW, but additional turbines were included in analysis regardless of power output. Specific exposure details: Sound pressure in A-weighted decibels (dB(A)) ^a outside residences averaged over time with 8 m/s downwind; range = 21–54 dB(A), mean = 35 dB(A). Frequency range of sound not reported; i.e., exposure profile in terms of audible noise versus infrasound not analysed. ^a Sound power levels collected from reports by consultancies, manufacturers and local authorities, or, where data were unavailable (older/smaller machines), the sound power level of a turbine with the same dimensions and electrical output was used; propagation of sound from turbines was calculated in		Control(s) description [8] No non-exposed groups were included in the study. A distribution of different sound level exposures was included (see 'Specific exposure details' and 'Population characteristics'). Sample size [9] See 'Population characteristics'. Survey sample selected from addresses provided by Land Registry Office – for each subgroup either a random sample was selected or all addresses that matched postcodes within 2.5 km of selected wind turbines. Subgroups were: rural area, rural area with a major road, densely populated built-up area.

accordance with the ISO standard model (see ISO 1996, 'Attenuation of sound during propagation outdoors. Part 2: General method of calculation', ISO 9613-2, International Organization for Standardization, Geneva).						
Sample size [7]						
Total, n=1948; respondents, n=725; non-respondents, n=1223; response rate 37%.						
Population characteristics [10]						
	Estimated sound pressure level, in dB(A)					
	<30	30–35	36–40	41–45	>45	Total
Study sample, n	491	589	421	250	197	1948
Respondents, n (%)						
Built-up area	68 (37)	84 (38)	28 (17)	18 (19)	1 (2)	199 (23)
Rural with main road	50 (27)	70 (32)	59 (38)	36 (38)	30 (46)	245 (36)
Rural without main road	67 (36)	65 (30)	75 (47)	40 (43)	34 (52)	281 (41)
Total	185 (38)	219 (37)	162 (38)	94 (38)	65 (33)	725 (100)
Age, mean (years)	NR	NR	NR	NR	NR	51
Sex, % male	NR	NR	NR	NR	NR	51
Length of follow-up [11]				Outcome(s) measured and/or analyses undertaken [12]		
NA (cross-sectional study design)				(a) psychological distress as determined by self-administered General Health Questionnaire (GHQ-12) [validated]; (b) chronic disease and a range of specific health states (see 'Results'), stress and sleep quality as per non-validated survey constructed by van den Berg et al.; (c) relationship between turbine sound exposure and self-reported health states (including chronic disease) considered at (b); (d) annoyance due to visual factors and vibration.		

INTERNAL VALIDITY Confounding subscale [13] <i>Comment on sources of confounding:</i> Few details on characteristics of participating population were reported. Adjustments made for influence of age, gender, education, employment, terrain, type of dwelling, urbanisation, economic benefit from turbines, background noise, noise sensitivity, attitude to turbines and turbine visibility. Findings may be partly explained by differences in levels of background sound between rural and urban areas. Covariates varied between analyses. Plausible confounders that were not addressed included socioeconomic status, chronic disease and risk factors for chronic disease, and occupation. Bias subscale [14] <i>Comment on sources of bias:</i> High potential for sample selection bias due to low response rate. It is uncertain whether participants were effectively masked regarding the purpose of the survey (recall bias). Equal weight was given to questions regarding other environmental factors but it is unclear whether study intent was known, leading to the possibility of responder bias (conscious or unconscious). Non-responder analysis conducted but only on 95 of the 200 randomly selected non-responders (non-responders=1223), so may not be representative.	EXTERNAL VALIDITY Generalisability [15] Survey mailed to a sample of households within 2.5 km of wind turbines; potential for differences between the total population living near the included wind farms and those that responded to questionnaire. Applicability [16] Unknown whether the population characteristics and the wind turbine exposures of those living near wind farms in The Netherlands are comparable to those living near wind farms in Australia.
Reporting subscale [17] <i>Comment on quality of reporting:</i> Main deficit is that information was not provided on characteristics of non-responders. Overall, though, reporting of study results in the full report was good.	
Chance [18] Statistical adjustments for undertaking multiple statistical tests were not reported.	
Overall quality assessment (descriptive) [19] On the basis of the Internal Validity assessment made above, and the detailed critical appraisal of the study given in Table 7, this study is considered poor quality for the purpose of this review. There was some adjustment for potential confounding, although a few plausible confounders were not addressed. There is potential for recall bias and outcome misclassification due to uncertainty in the effectiveness of masked study intent and inclusion of non-standard survey questions, respectively. There is a high risk of exposure misclassification (time criterion was not well-defined), sample selection bias (37% response rate) and statistically significant associations occurring due to chance (multiple statistical tests and no Bonferroni correction).	

RESULTS

Adverse effect outcomes [20]

Self-reported health and sleep in relation to estimated sound pressure level.

	Estimated sound pressure level, in dB(A)					
	<30	30–35	36–40	41–45	>45	Total
Chronic disease (n=717), %	32	25	25	18	15	25
Diabetes (n=725), %	4	4	4	2	3	4
High blood pressure (n=725), %	9	13	9	6	2	9
Tinnitus (n=725), %	4	3	1	1	2	2
Hearing impairment (n=725), %	4	6	3	3	2	4
Cardiovascular disease (n=725), %	6	7	8	1	0	6
Migraine (n=725), %	4	2	2	1	0	2
GHQ-12 score (n=656), mean±SD	3.2±2.78	3.1±2.66	3.8±2.91	3.8±2.81	3.6±2.76	3.4±2.79
Stress score (n=656), mean±SD	0.1±1.04	−0.1±0.93	0.1±0.9	0.0±0.91	−0.1±1.02	0.0±0.0
Sleep quality						
Difficulty falling asleep ^a (n=710), %	36	31	28	32	16	30
Interrupted sleep ^a (n=718), %	21	26	26	26	28	25

^a At least once a month.

Relationship between estimated sound exposure and self-reported health states including chronic disease (logistic regression) for all respondents.

Note: these results comprise part of the data shown in results tables for Pedersen et al. (2009) (excluding migraine), which adjusted for age, sex and economic benefits.

	Odds ratio	95% CI
Chronic disease:	0.98	[0.95, 1.01]
Diabetes	1.00	[0.92, 1.09]
High blood pressure	1.01	[0.96, 1.06]
Tinnitus	0.94	[0.85, 1.04]
Hearing impairment	1.01	[0.94, 1.10]
Cardiovascular disease	0.98	[0.91, 1.05]
Migraine	0.93	[0.83, 1.04]

Annoyance due to visual factors and vibration for all respondents (not stratified by sound exposure group.)

	Blinking shadows indoors	Moving shadows outdoors	Movement of rotor blades	Changed view	Vibrations
Respondents annoyed, n (%)					
Slightly	75 (11)	63 (9)	70 (10)	91 (14)	18 (3)
Rather	20 (3)	15 (2)	30 (5)	48 (7)	4 (1)
Very	19 (3)	23 (4)	27 (4)	42 (6)	3 (0)
Total annoyed	114/669 (17)	101/665 (15)	127/667 (19)	181/665 (27)	25/638 (4)
Frequency of annoyance, n (%)					
Almost never	529 (80)	520 (79)	498 (76)	442 (68)	615 (96)
≥Once in past year	44 (7)	43 (7)	31 (5)	46 (7)	9 (1)
≥Once per month	38 (6)	37 (6)	27 (4)	29 (4)	7 (1)
≥Once per week	30 (5)	27 (4)	26 (4)	22 (3)	7 (1)
Almost daily	23 (3)	32 (5)	73 (11)	113 (17)	6 (1)
Total	663 (100)	659 (100)	665 (100)	652 (100)	644 (100)

Exposure group [21]	Control group [22]	Measure of effect / effect size [23]	Harms (NNH) [24]
See 'Adverse effect outcomes' [20].	NA	95% CI [25] See [20].	95% CI [25] See [20].

Public health importance (1–4) [26]	Relevance (1–5) [27]
Ranked 3 for overall chronic disease outcome. Ranked 3 or 4 for health outcomes taken singly.	1

Comments [28]
This study was cross-sectional in design. This does not permit any conclusions regarding causation between health outcomes and noise exposure from turbines; that is, it is unknown whether the self-reported health outcomes occurred prior to or after exposure. Health outcomes did not appear related to estimated sound exposure. Annoyance was considered, but it is not a health outcome and it is uncertain whether it is associated with stress which may be a mediating variable for health. The study has limited capacity to inform the assessment of wind turbine noise as a cause of adverse health effects.

ARTICLE DETAILS		
Reference [1] Krogh, CME, Gillis, L, Kouwen, N & Aramini, J 2011 , 'WindVOiCe, a self-reporting survey: adverse health effects, industrial wind turbines, and the need for vigilance monitoring', <i>Bulletin of Science, Technology & Society</i> , vol. 31(4), pp. 334–345.		
Affiliation/source of funds [2] Killaloe, Flesherton, University of Waterloo, Waterloo and Intelligent Health Solutions, Fergus, Ontario, Canada.		
Study design [3] Cross-sectional study	Level of evidence [4] IV	Location/setting [5] Residents in five project areas in Ontario, Canada, where adverse health effects had been anecdotally reported: Melancthon Phase 1 and 2 (Shelburne), Canadian Hydro Wind Developers (Shelburne), Kingsbridge 1 Wind Power (Goderich), Kruger Energy Port Alma (Port Alma), Ripley Wind Power (Ripley), Enbridge Ontario Wind Farm (Kincardine) and Erie Shores Wind Farm (Port Burwell). Proximity/distance: Distance to nearest wind turbine was divided into four groups based on natural break-points among the participants: 350–499 m, 500–699 m, 700–899 m, and 900–2400 m.
Exposure description [6] Wind farm details sourced from: http://en.wikipedia.org/wiki/List_of_wind_farms_in_Canada <i>Melancthon Phase 1 and 2 (Amaranth)</i> , commenced operation in March 2006 133 General Electric SLE 1.5-MW turbines, sited in a farming community Turbine height = 80 m Rotor diameter = 77 m <i>Kingsbridge 1 Wind Power (Goderich)</i> , commenced	Control(s) description [8] No non-exposed groups were included in the study. Sample size [9] See 'Population characteristics'.	

operation in March 2006
 22 Vestas V80 1.8-MW turbines, sited on the southeast shore of Lake Huron
 Turbine height = 78 m
 Rotor diameter = 80 m

Kruger Energy Port Alma (Port Alma), commenced operation in November 2008
 44 Siemens 2.3-MW Mark II turbines, sited on the north shore of Lake Erie
 Turbine height = 80 m
 Rotor diameter = 82.5 m

Ripley Wind Power (Ripley), commenced operation in December 2007
 38 Enercon E-82 2.0-MW turbines, sited along the shore of Lake Huron
 Turbine height = 79 m
 Rotor diameter = 82 m

Enbridge Ontario Wind Farm (Kincardine), commenced operation in August 2008
 110 Vestas V82 1.65-MW turbines, sited along the shore of Lake Huron
 Turbine height = 80 m
 Rotor diameter = 82 m

Erie Shores Wind Farm (Port Burwell), commenced operation in April 2006
 66 General Electric SLE 1.5-MW turbines, sited along the shore of Lake Erie
 Turbine height = 80 m
 Rotor diameter = 77 m

Specific exposure details:
 Not reported.

Sample size [7]

A Health Survey Contact Flyer was distributed by Canada Post and hand-delivered by volunteers to mailboxes in the areas where the wind turbines were located.

n=103 respondents; 6 were excluded; 4 were under 18 years of age and 2 were much further away (5 km) than the remaining respondents (350–2400 m).

Respondents were divided into subgroups according to distance from nearest wind turbine:

24% adults living mean 428 m (range 350–490 m) from nearest wind turbine

23% adults living mean 587 m (range 500–67 m) from

nearest wind turbine 30% adults living mean 769 m (range 700–808 m) from nearest wind turbine 17% adults living mean 1154 m (range 900–2400 m) from nearest wind turbine	
Population characteristics [10] Exposure group: n=103 respondents; mean age = 52 years (range 18–83); female = 52%. Control group(s): None.	
Length of follow-up [11] NA (cross-sectional study). Length of exposure: Wind farms commenced operation between March 2006 and November 2008 (see details above). Survey started in March 2009.	Outcome(s) measured and/or analyses undertaken [12] Health outcomes measured by self-reporting survey.
INTERNAL VALIDITY Confounding subscale [13] Comment on sources of confounding: Few details on participant characteristics and none for non-responders. Only gender was taken into account for some analyses. Many other plausible confounders not addressed ie economic factors, age, chronic disease and risk factors for chronic disease, occupation, education, employment, terrain, urbanisation, background noise, and turbine visibility. Bias subscale [14] Comment on sources of bias: The intent of the study was not masked from survey recipients (recall bias). Sampling area was chosen because adverse health effects had been reported there (sample selection bias). Possible clustering by household as multiple adults from same household were able to respond (sample selection bias).	EXTERNAL VALIDITY Generalisability [15] Potential for differences between the total population living near the included wind farms and those that participated in the survey. Applicability [16] Uncertain whether the population characteristics and the wind turbine exposures of those living near wind farms in Ontario, Canada, are applicable to those living near wind farms in Australia.
Reporting subscale [17] Comment on quality of reporting: No reporting on participant characteristics (except age and gender of all participants), or on the characteristics of non-responders. No reporting on survey response rate.	
Chance [18] The possibility of spurious significant associations arising by chance cannot be excluded as multiple statistical	

tests were conducted.

Overall quality assessment (descriptive) [19]

On the basis of the Internal Validity assessment made above, and the detailed critical appraisal of the study given in Table 7, this study is considered poor quality for the purpose of this review.

There is potential for sample selection bias as the response rate was not reported. The outcomes were patient-relevant but not reliably measured. There is a high risk of exposure misclassification (time and personal characteristics criteria were not well-defined), recall bias (study intent not masked), outcome misclassification (non-validated survey questions), confounding and statistically significant associations occurring due to chance (multiple statistical tests and no Bonferroni correction).

RESULTS

Adverse effect outcomes [20]	Exposure group [21]					Control group [22]	Harms (NNH) [24] 95% CI
						Measure of effect / effect size [23] 95% CI [25]	
	Mean distance from turbine: Subgroups:					p (Fisher's exact)	NC
	428 m	587 m	769 m	1154 m	Total: 707 m		
Altered quality of life	96%	96%	100%	94%	97%	p = 1.00	
Altered health	93%	96%	87%	82%	90%	p = 0.19	
Disturbed sleep	78%	78%	60%	59%	69%	p = 0.08	
Excessive tiredness	89%	83%	63%	71%	76%	p = 0.03	
Increased headaches	74%	65%	60%	41%	62%	p = 0.10	
Migraines	22%	13%	13%	0%	13%	p = 0.24	
Hearing problems	22%	57%	27%	41%	35%	p = 0.67	
Tinnitus	59%	61%	33%	41%	56%	p = 0.42	
Heart palpitations	26%	39%	33%	37%	34%	p = 0.68	
Stress	74%	57%	70%	76%	69%	p = 0.52	
Anxiety	52%	57%	40%	65%	52%	p = 0.68	
Depression	44%	48%	33%	41%	41%	p = 0.41	
Distress	74%	61%	73%	82%	72%	p = 0.38	
Approached doctor	37%	39%	49%	35%	38%	p = 1.00	
	Public health importance (1–4) [26]					Relevance (1–5) [27]	
	Cannot be determined based on NHMRC criteria.					1	

Comments [28]

Nearly all respondents suffered from altered quality of life and/or altered health. However, this study was cross-sectional in design and so does not permit any conclusions regarding causation between health outcomes and noise exposure from turbines; that is, it is unknown whether the self-reported health outcomes occurred prior to or after exposure.

It is unknown how many people were approached but did not respond to the survey. It is possible that those suffering no ill effects did not respond to this survey as it required contacting the WindVOiCe survey team to participate. The only statistically significant difference between groups near and far from the turbines was excessive tiredness. Although not statistically significant (and an unadjusted analysis), the number of people suffering from self-reported headaches, migraines and sleep disturbances had a linear relationship with distance from nearest wind turbine. The number of people suffering from self-reported tinnitus also decreased if living further from, as opposed to closer to, the nearest turbine.

The study has limited capacity to inform the assessment of wind turbine noise as a cause of adverse health effects.

ARTICLE DETAILS		
Reference [1] Morris, M 2012. 'Waterloo Wind Farm survey'. Available at: < http://www.wind-watch.org/news/ >.		
Affiliation/source of funds [2] 'Mid North Wind Farm Awareness' member.		
Study design [3] Cross-sectional survey	Level of evidence [4] IV	Location/setting [5] Waterloo Wind Farm, North Mount Lofty Ranges, South Australia. Proximity/distance: Within 10 km.
Exposure description [6] Wind farm details, sourced from: < http://en.wikipedia.org/wiki/Wind_power_in_South_Australia#Waterloo_Wind_Farm_.28111_MW.29 > and < http://www.energyaustralia.com.au/about-us/what-we-do/generation-assets/waterloo-wind-farm > 37 turbines (Vestas V90-3.0 MW) sited on a ridgeline Turbine height = 80 m Rotor diameter = 90 m Specific exposure details: Typical noise exposure range not reported. Sample size [7] n=230 households received an anonymous survey Responders in 0–10 km range: n=93 households, n=270 residents Response rate = 40%. Subgroup in 0–5 km range: n=41 households, n=92 residents		Control(s) description [8] No non-exposed groups were included in the study. Participation determined by distance from wind turbines (0–10 km), with a subgroup of participants 0–5 km from turbines. Sample size [9] NA
Population characteristics [10] Exposure group: Households within approximately 10 km of the Waterloo Wind Farm, SA. Control group(s): None.		

Length of follow-up [11] NA Length of exposure: Wind farm commenced operation in October 2010. Survey conducted in April 2012.	Outcome(s) measured and/or analyses undertaken [12] Annoyed by flickering, disturbed sleep, affected by noise (includes: cannot get to sleep, get woken up, cannot get back to sleep, wake up in a panic, wake up in a sweat, broken/disturbed sleep, ear pain/ear pressure/tinnitus, headache, nausea, had to move away to get sleep, high blood pressure when wake up, ears hurt which makes sleep difficult).
INTERNAL VALIDITY Confounding subscale [13] <i>Comment on sources of confounding:</i> No details on responder characteristics or plausible confounders e.g. socioeconomic status, economic factors, age, gender, chronic disease and risk factors for chronic disease, occupation, education, employment, urbanisation, background noise, wind turbine visibility and terrain. Bias subscale [14] <i>Comment on sources of bias:</i> There was no clear definition of what 'affected by noise' included. Self-reporting survey, hence no independent confirmation of claimed adverse effects. Differences between responders and non-responders were not assessed. Study intent was not masked for survey recipients.	EXTERNAL VALIDITY Generalisability [15] Survey distributed to all households within proximity of a wind farm / wind turbines. Applicability [16] Survey conducted in Australia.
Reporting subscale [17] <i>Comment on quality of reporting:</i> There was no clear description of main outcomes, participant characteristics, exposure level or any differences between responders and non-responders.	
Chance [18] No data analysis.	
Overall quality assessment (descriptive) [19] On the basis of the Internal Validity assessment made above, and the detailed critical appraisal of the study given in Table 7, this study is considered poor quality for the purpose of this review. There is a high risk of exposure misclassification (time and personal characteristics criteria were not well-defined), recall bias (study intent not masked), sample selection bias (40% response rate), confounding (no statistical adjustments were made), and outcome misclassification (non-validated survey questions).	

RESULTS				
Adverse effect outcomes [20]	Exposure group [21]	Subgroup [22]	Measure of effect / effect size [23]	Harms (NNH) [24]
Distance from turbine:	0–10 km (all responders)	0–5 km (subgroup)	95% CI [25]	95% CI [25]
Disturbed sleep	27/93 (29%)	16/41 (39%)	NC	NC
Seriously affected	7/44 (16%)	6/25 (24%)		
Moderately affected	17/44 (39%)	10/25 (40%)		
	Public health importance (1–4) [26]		Relevance (1–5) [27]	
	Not able to determine from the NHMRC criteria.		5	
Comments [28]				
The study was quasi-scientific and of poor quality. The study design, poor execution and analysis prevent any firm conclusions from being drawn. The study has limited capacity to inform the assessment of wind turbine noise as a cause of adverse health effects.				

ARTICLE DETAILS																													
Reference [1] Nissenbaum, M, Aramini, J & Hanning, C 2012, 'Effects of industrial wind turbine noise on sleep and health', <i>Noise & Health</i>, vol. 14, pp. 237–243.																													
Affiliation/source of funds [2] Northern Maine Medical Center, Fort Kent, Maine, USA; Intelligent Health Solutions Inc., Fergus, Ontario Canada; University Hospitals of Leicester, Leicester, UK.																													
Study design [3] Cross-sectional study.	Level of evidence [4] IV	Location/setting [5] Residences of Mars Hill and Vinalhaven, Maine, USA. Proximity/distance: Exposed residences located within 1.5 km of nearest industrial wind turbine; control residences were located 3–7 km from nearest turbine.																											
Exposure description [6] Wind farm details: <i>Mars Hill site</i> 28 General Electric 1.5-MW turbines, sited on a ridgeline. <i>Vinalhaven site</i> Cluster of 3 turbines of similar specification to Mars Hill site, sited on a flat tree covered island. Specific exposure details: Mars Hill full power measurements were derived from a four-season study. Vinalhaven measurements taken in February 2010, during moderate-to-variable northwest winds with turbines at less than full power: <table> <tr> <th></th><th><i>Mars Hill</i></th><th><i>Vinalhaven</i></th></tr> <tr> <td>Distance from turbine</td><td></td><td></td></tr> <tr> <td>Measured noise</td><td></td><td>Measured noise</td></tr> <tr> <td><i>LA_{eq, 1 hour}</i> (range)</td><td></td><td><i>LA_{eq, 1 hour}</i> (range)</td></tr> <tr> <td>366</td><td>49 (47–52)</td><td>46 (38–49)</td></tr> <tr> <td>595</td><td></td><td>41 (39–49)</td></tr> <tr> <td>640</td><td>44 (40–47)</td><td></td></tr> <tr> <td>762</td><td>43 (41–46)</td><td></td></tr> <tr> <td>869</td><td></td><td>38 (32–41)</td></tr> </table>			<i>Mars Hill</i>	<i>Vinalhaven</i>	Distance from turbine			Measured noise		Measured noise	<i>LA_{eq, 1 hour}</i> (range)		<i>LA_{eq, 1 hour}</i> (range)	366	49 (47–52)	46 (38–49)	595		41 (39–49)	640	44 (40–47)		762	43 (41–46)		869		38 (32–41)	Control(s) description [8] See 'Proximity/distance' for details; whether this control group can be considered truly unexposed is uncertain as criteria for the present review do not specify a cut-off for exposure by distance, and this group may alternatively be considered as 'partially exposed'. Sample size [9] n=41 adult (>18 years of age) respondents among 41 adults identified to be living within 3–7 km from nearest turbine n=25 living around Mars Hill n=16 living around Vinalhaven. Response rate = not reported.
	<i>Mars Hill</i>	<i>Vinalhaven</i>																											
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1037	41 (39–45)																																						
1082		36 (34–43)																																					
1799	37 (32–43)																																						
Sample size [7] n=38 adult (>18 years of age) respondents among 65 adults identified to be living within 1.5 km of nearest turbine n=23 adults living mean 805 m (range 390–1400 m) from Mars Hill n=15 adults living mean 771 m (range 375–1000 m) from Vinalhaven. Response rate = 58%.																																							
Population characteristics [10] <table border="1"> <thead> <tr> <th></th><th colspan="4">Distance range from turbines</th></tr> <tr> <th></th><th colspan="2">Exposure group (near)</th><th colspan="2">Control group (far)</th></tr> </thead> <tbody> <tr> <td>Distance (m) from nearest turbine, mean (range)</td><td>601 (375–750)</td><td>964 (751–1400)</td><td>4181 (3300–5000)</td><td>5800 (5300–6600)</td></tr> <tr> <td>Sample size, n</td><td>18</td><td>20</td><td>14</td><td>27</td></tr> <tr> <td>Household clusters, n</td><td>11</td><td>12</td><td>10</td><td>23</td></tr> <tr> <td>Age, years (mean)</td><td>50</td><td>57</td><td>65</td><td>58</td></tr> <tr> <td>Male, n (%)</td><td>10 (55.6)</td><td>12 (60)</td><td>7 (50)</td><td>11 (40.7)</td></tr> </tbody> </table>						Distance range from turbines					Exposure group (near)		Control group (far)		Distance (m) from nearest turbine, mean (range)	601 (375–750)	964 (751–1400)	4181 (3300–5000)	5800 (5300–6600)	Sample size, n	18	20	14	27	Household clusters, n	11	12	10	23	Age, years (mean)	50	57	65	58	Male, n (%)	10 (55.6)	12 (60)	7 (50)	11 (40.7)
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Length of follow-up [11] NA (cross-sectional study). Length of exposure: Mars Hill commenced operation in March 2007. Vinalhaven commenced operation in December 2009. Survey conducted in March–July 2010.		Outcome(s) measured and/or analyses undertaken [12] Sleep quality as determined by the Epworth Sleepiness Scale (ESS) and Pittsburgh Sleep Quality Index (PSQI); health as per responses to physical and mental health components of the Short Form (36) Health Survey, version 2 (SF-36v2). Questionnaires are validated.																																					

INTERNAL VALIDITY Confounding subscale [13] <i>Comment on sources of confounding:</i> Few details on participant characteristics and none for non-responders. Confounders taken into account included age, gender, site and household clustering. The impact of economic benefit from turbines was not controlled for despite the authors acknowledging that residents of Mars Hill and Vinalhaven benefited financially from wind farms in their area. Turbine visibility was not taken into account in the analysis. Other plausible confounders also not addressed e.g. socioeconomic status, chronic disease and risk factors for chronic disease, occupation, education, employment, terrain, urbanisation and background noise. Bias subscale [14] <i>Comment on sources of bias:</i> It was not possible to mask participants to their exposure level to turbine noise but the intent of the survey was also not masked (recall bias). 58% response rate in exposed group (sample selection bias). The possibility of confounding due to differences in the distribution of economically benefiting residents in the 'near' and 'far' groups cannot be excluded.	EXTERNAL VALIDITY Generalisability [15] Approached all adults identified as living in close proximity to the wind farms for intervention group. Applicability [16] Uncertain whether the population characteristics and the wind turbine exposures of those living near wind farms in Mars Hill and Vinalhaven in Maine, USA, are applicable to those living near wind farms in Australia.
Reporting subscale [17] <i>Comment on quality of reporting:</i> Overall good reporting except for participant characteristics such as general state of health, previous depression, anxiety or sleep problems and the characteristics of non-responders.	
Chance [18] The possibility of spurious significant associations arising by chance cannot be excluded as multiple statistical tests were conducted.	
Overall quality assessment (descriptive) [19] Although exposure ascertainment was partly directly measured and there was good reporting of some study characteristics and adjustment for potential confounders, other plausible confounders were not measured or adjusted and the study intent was not masked. Outcome misclassification was less of a problem due to the use of validated instruments/scales. There is, therefore, a high risk of recall bias, sample selection bias, confounding, statistically significant associations occurring due to chance and exposure misclassification. For further critical appraisal of the study, see Table 7.	

RESULTS				Harms (NNH) [24] 95% CI		
				See [20].		
Adverse effect outcomes [20]	Exposure group [21] (near)			Control group [22] (far)		
	Mean distance from turbine:			Mean distance from turbine:		
	Subgroups:		Total:	Subgroups:		Total:
	601 m	964 m	792 m	4181 m	5800 m	5248 m
PSQI, mean	8.7	7.0	7.8	6.6	5.6	6.0
n (%) PSQI score >5	14/18 (77.8%)	11/20 (55.0%)	25/38 (65.8%)	8/14 (57.1%)	10/27 (37.0%)	18/41 (43.9%)
ESS, mean	7.2	8.4	7.8	6.4	5.3	5.7
n (%) ESS score >10	3/18 (16.7%)	6/20 (30.0%)	9/38 (23.7%)	2/14 (14.3%)	2/27 (7.4%)	4/41 (9.8%)
Mean worse sleep post turbines						
score (1–5 scale)	3.2	3.1	3.1	1.2	1.4	1.3
n (%) improved sleep away from turbines	9/14 (64.3%)	5/14 (35.7%)	14/28 (50.0%)	1/11 (9.1%)	1/23 (4.3%)	2/34 (5.9%)
n (%) new sleep medications post turbines	2/18 (11.1%)	3/20 (15.0%)	5/38 (13.2%)	1/14 (7.1%)	2/27 (7.4%)	3/41 (7.3%)
n (%) new diagnosis of insomnia			2/38 (5.3%)			0/41 (0%)
n (%) new diagnosis of depression or anxiety			9/38 (23.7%)			0/41 (0%)
n (%) prescribed new psychotropic medications post turbines			9/38 (23.7%)			3/41 (7.3%)
SF-36 MCS ^a , mean	40.7	43.1	42.0	50.7	54.1	52.9
SF-36 PCS ^b , mean	NR			NR		
n (%) wishing to move away post turbines	14/18 (77.8%)	14/20 (70.0%)	28/38 (73.7%)	0/14 (0%)	0/27 (0%)	0/41 (0%)
^a Mental component score	Public health importance (1–4) [26]			Relevance (1–5) [27]		
^b Physical component score	PSQI score			2		
	ESS score			2		
	Improved sleep away from turbine			1		
	New sleep medication			2		
	New medication (psychotropic)			2		
				1		
				RR = 1.50 (0.99, 2.27)		
				p = 0.075		
				p = 0.032		
				RR = 2.43 (0.81, 7.23)		
				p = 0.131		
				p <0.0001		
				RR = 8.5 (2.11, 34.3)		
				p <0.0001		
				RR = 1.80 (0.46, 7.02)		
				p = 0.47		
				RR not calculable		
				p = 0.23		
				RR not calculable		
				p = 0.001		
				RR = 3.24 (0.94, 11.1)		
				p = 0.06		
				p = 0.002		
				no difference, p = 0.99		
				RR not calculable		
				p <0.0001		

Comments [28]

Although there were statistically significant differences in the mean scores for the 2 sleep questionnaires and the mental health component of the SF-36 questionnaire, there was no statistically significant difference in the overall number of people affected between the near and far groups. The cross-sectional design of the study and the way it has been executed/analysed means that there is a high risk of recall bias, sample selection bias, confounding, statistically significant associations occurring due to chance and exposure misclassification. The study has limited capacity to inform the assessment of wind turbine noise as a cause of adverse health effects.

ARTICLE DETAILS			
Reference [1] Shepherd , D, McBride, D, Welch, D, Dirks, KN & Hill, EM 2011 , 'Evaluating the impact of wind turbine noise on health-related quality of life', <i>Noise & Health</i> , vol. 13, no. 54, pp. 333–339.			
Affiliation/source of funds [2] Auckland University of Technology, New Zealand, University of Otago, New Zealand, and The University of Auckland, New Zealand.			
Study design [3] Cross-sectional	Level of evidence [4] IV	Location/setting [5] Makara Valley, New Zealand; hilly terrain with long ridges 250–450 m above sea level. Proximity/distance: Exposed participants in dwellings (n=56 homes) <2 km from the nearest wind turbine; non-exposed controls resided (n=250 homes) ≥8 km from a turbine.	
Exposure description [6] Wind farm details: 66 turbines (Siemens SWT-2.3-82 VS) Turbine height = 125 m Rotor diameter = 82 m Specific exposure details: Typical noise exposure range = 24–54 dB(A). Sample size [7] Each household received 2 questionnaires, generating a sample of ≈112, with 39 respondents and response rate = 34% (sample is approximate because only individuals aged >18 years could respond).		Control(s) description [8] Socioeconomic and geographic matched sample differing from the exposure group only by distance from wind turbines (≥8 km). Sample size [9] ≈500, with 158 respondents and response rate = 32% (further details as per exposed group sample size).	
Population characteristics [10]			
	Exposure group (near), n=39		Control group (far), n=158
<i>Variables</i>	n	(%)	n (%)
Sex, n (%) male	16	(41)	63 (41)
Age group, years			
18–20	1	(2.6)	2 (1.2)
21–30	1	(2.6)	1 (0.5)
31–40	5	(12.8)	22 (13.9)
41–50	10	(25.6)	53 (33.5)
51–60	11	(28.2)	44 (27.8)

61–70	7 (17.9)	27 (17.1)
≥71	3 (7.7)	9 (5.6)
Education (completed)		
High school	11 (28.2)	55 (34.8)
Polytechnic	11 (28.2)	48 (30.3)
University	17 (43.6)	54 (34.2)
Employment status		
Full time	21 (53.8)	83 (52.5)
Part time	0 (0)	3 (1.8)
Unpaid work	1 (2.6)	3 (1.8)
Unemployed	6 (15.3)	27 (17.1)
Retired	10 (25.6)	40 (25.3)
Noise sensitivity		
None	13 (33.3)	60 (37.9)
Moderate	21 (55.3)	76 (48.1)
Severe	5 (12.8)	20 (12.7)
Current illness		
Yes	10 (27)	50 (31.6)
No	27 (69.2)	104 (65.8)
Length of follow-up [11] NA (cross-sectional study).		Outcome(s) measured and/or analyses undertaken [12] Quality of life as determined by self-administered brief version of the World Health Organization (WHO) quality of life (WHOQOL-BREF) scale (26 items) [validated], plus additional questions on amenity (2 items), neighbourhood problems (14 items), annoyance (7 items), demographic information (7 items) and a single item probing noise sensitivity.
INTERNAL VALIDITY Confounding subscale [13] <i>Comment on sources of confounding:</i> Unequal distribution of some baseline characteristics between 'near' and 'far' groups, although not statistically significant. Socioeconomic and geographic matching undertaken and adjustment by length of residence. Unclear whether there was any clustering effect of responses as two questionnaires delivered to each household. Other plausible confounders not addressed ie age, education, chronic disease and risk factors for chronic disease, occupation, employment, background noise, and turbine visibility. Bias subscale [14] <i>Comment on sources of bias:</i>		EXTERNAL VALIDITY Generalisability [15] Survey sample members were either within 2 km of a turbine (exposed) or more than 8 km from a turbine (non-exposed); potential for differences between the total population living near the included wind farms and those that responded to questionnaire. Applicability [16] Unknown whether the population characteristics and the wind turbine exposures of those living near wind farms in New Zealand are comparable to those living near wind farms in Australia.

Very poor response rate for both turbine and comparison groups, and it is unclear whether self-selection could have introduced any selection bias in terms of important differences between the two groups—although study intent was masked.									
Reporting subscale [17] Comment on quality of reporting: Good.									
Chance [18] Statistical adjustments for undertaking multiple statistical tests were reported (Bonferroni correction).									
Overall quality assessment (descriptive) [19] On the basis of the Internal Validity assessment made above, and the detailed critical appraisal of the study given in Table 7, this study is considered poor quality for the purpose of this review. There is a high risk of exposure misclassification (time criterion was not well-defined), sample selection bias (~34% response rate), and confounding. There is also the potential for outcome misclassification (some non-validated survey questions) and recall bias (unclear if masking of study intent was effective).									
RESULTS									
Adverse effect outcomes [20] <i>Pearson product-moment correlation coefficients (r) for noise-related and QoL variables. Statistics to the right of the major diagonal are for the control group, while those to the left are for the exposure group.</i>									
					QoL				
	Sensitivity	Annoyance	Sleep	Health	Physical	Psychological	Social	Environment	Overall
Sensitivity	1	0.134	−0.017	0.082	−0.017	−0.069	0.006	−0.666	−0.109
Annoyance	0.440 ^b	1	0.042	−0.258 ^b	−0.209 ^a	−0.135	−0.155 ^a	−0.319 ^b	−0.097
Sleep	−0.433 ^b	−0.147	1	0.337 ^b	0.378 ^b	0.489 ^b	0.327 ^b	0.279 ^b	0.198 ^a
Health	−0.234	−0.308	0.471 ^b	1	0.706 ^b	0.493 ^b	0.158 ^b	0.284 ^b	0.327 ^b
Physical	−0.24	−0.212	0.364 ^a	0.524 ^b	1	0.655 ^b	0.29 ^b	0.455 ^b	0.475 ^b
Psychological	−0.404	−0.113	0.473 ^b	0.329 ^a	0.268	1	0.55 ^b	0.608 ^b	0.589 ^b
Social	−0.359	−0.236	0.116	−0.021	0.036	0.212	1	0.456 ^b	0.45 ^b
Environment	−0.235	0.028	0.404 ^b	0.200	0.474	0.468 ^a	−0.17	1	0.546 ^b
Overall	−0.203	0.160	0.471 ^b	0.289	0.282	0.286	0.162	0.380 ^a	1
QoL = quality of life									
^a p<0.05									
^b p<0.001									
^c Questionnaire item 16 (satisfaction with sleep) was removed from the Physical QoL domain when correlated with sleep satisfaction									

Mean statistics for the four QoL domains of the WHOQOL-BREF total scores.

Measure, mean±SD	Exposure group	Control group	p value, between-group difference
Physical	27.38±3.14	29.14±3.89	0.017
Psychological	22.36±2.67	23.29±2.91	0.069
Social	12.53±1.83	12.54±2.13	0.963
Environmental	29.92±3.76	32.76±4.41	0.018
Amenity	7.46±1.42	8.91±2.64	<0.001

QoL=quality of life, SD=standard deviation

Physical domain: maximum score of 35; psychological domain: maximum score of 30; social domain: maximum score of 15; environmental domain: maximum score of 40. Amenity domain was added to the questionnaire by the authors.

Exposure group [21]	Control group [22]	Measure of effect / effect size [23]	Harms (NNH) [24]
See 'Adverse effect outcomes' [20].	See 'Adverse effect outcomes' [20].	95% CI [25] See [20].	95% CI [25] See [20].

Public health importance (1–4) [26]	Relevance (1–5) [27]
Physical QoL: rank of 4 Psychological QoL: rank of 4 Social QoL: rank of 4	1

Comments [28]
This study was cross-sectional in design. This does not permit any conclusions regarding causation between health outcomes and noise exposure from turbines; that is, it is unknown whether the self-reported health outcomes occurred prior to or after exposure. Even though important QoL endpoints were selected, the differences between groups are small and potentially attributable to factors other than wind turbine exposure, given the lack of adjustment for other plausible confounders. The study has limited capacity to inform the assessment of wind turbine noise as a cause of adverse health effects.

ARTICLE DETAILS		
Reference [1] Pedersen , E & Persson Waye, KP 2004 , 'Perception and annoyance due to wind turbine noise: a dose-response relationship', <i>Journal of the Acoustical Society of America</i> , vol. 116, no. 6, pp. 3460–3470.		
Affiliation/source of funds [2] Department of Environmental Medicine, Göteborg University, Göteborg, Sweden. Funded through grant P13644-1 from the Swedish Energy Agency and Adlerberska Research Foundation.		
Study design [3] Cross-sectional study	Level of evidence [4] IV	Location/setting [5] Five areas within a 22-km ² region of southern Sweden. Landscape predominantly flat and mainly agricultural, but with small industries, roads and railroads present. Proximity/distance: Distance from dwelling of respondent to nearest turbine, range = 150–1199 m
Exposure description [6] Wind farm details: 14 towers within the study areas had a power output of 600–650 kW, 2 towers had outputs of 500 kW and 150 kW. Tower height, range = 47–50 m. Turbine make: 13 WindWorld, 2 Enercon, 1 Vestas. Specific exposure details: A-weighted (dB(A)) sound pressure levels due to turbines were estimated based on sound propagation models and calculated for each respondent's dwelling, grouped by 6 categories: <30.0, 30.0–32.5, 32.5–35.0, 35.0–37.5, 37.5–40.0 and >40.0 dB(A). Sample size [7] Total = 513; respondents, n=351; non-respondents, n=162; response rate 68%.		Control(s) description [8] No non-exposed groups were included in the study. Responder characteristics across different types of environmental exposure were reported (see 'Specific exposure details'). Sample size [9] See 'Population characteristics'.
Population characteristics [10] Exposure group:		

Estimated A-weighted sound pressure intervals in dB(A) ^a							
	<30.0	30.0–32.5	32.5–35.0	35.0–37.5	37.5–40.0	>40.0	Total
Study sample, n	25	103	200	100	53	32	513
Respondents, n	15	71	137	63	40	25	351
Response rate, %	60	68.9	68.5	63	75.5	78.1	68.4
Age, mean±SD	46±13.3	47±13.3	47±14.3	50±14.6	48±13.1	48±14.3	48±14.0
Sex, % male	27	35	39	50	50	48	42
Residence, detached house/farm %	100	83	61	100	97	96	81
Occupation, % employed	67	59	58	53	69	67	60
Sensitive to noise, %	62	44	49	53	58	50	50
Negative toward turbines, %	8	10	11	18	20	8	13
Negative to turbine visual impact, %	43	33	38	41	40	58	40
Long term illness, %	20	29	28	16	30	24	26
^a These are the intervals as reported by the authors. Note that the intervals are not mutually exclusive. For further details regarding the utility/relevance of results included in this paper, see 'Outcomes measured'. Abbreviations: SD = standard deviation							
Length of follow-up [11] NA (cross-sectional study)				Outcome(s) measured and/or analyses undertaken [12] Perception and annoyance due to wind turbine sound across the nominated estimated sound categories. Influence of subjective factors on annoyance (visual impact, attitude to turbines, noise sensitivity). Correlations between turbine noise annoyance, sound category and subjective variables (as above). Correlations between noise annoyance and verbal descriptors of noise (swishing, whistling, pulsating/throbbing, resounding, low frequency, scratching/squeaking, tonal, and lapping).			
INTERNAL VALIDITY Confounding subscale [13] <i>Comment on sources of confounding:</i> Analyses adjusted for some sources of confounding (age, gender, noise sensitivity, visual impact, attitude to turbines – covariates varied across analyses) but other plausible confounders not addressed i.e. socioeconomic status, economic factors, chronic disease and risk factors for chronic disease, occupation, education, employment, terrain,				EXTERNAL VALIDITY Generalisability [15] Survey delivered to a sample of households within ~1.2 km of wind turbines; potential for differences between the total population living near the included wind farms and those that responded to questionnaire. Applicability [16] Uncertain whether the population characteristics and			

urbanisation and background noise.	the wind turbine exposures of those living near selected Swedish wind farms are applicable to populations near wind farms in Australia.																																										
Bias subscale [14] Comment on sources of bias: Individuals experiencing more annoyance would have a higher tendency to fill in or return a questionnaire; therefore, potential for sample selection bias. 32% of people who received a survey did not respond. Masking of study intent was attempted but it is unknown whether it was successful (recall bias).																																											
Reporting subscale [17] Comment on quality of reporting: Good reporting of responder demographics according to sound exposure groups, although the characteristics of non-responders were not reported. The study did not report on economic benefits from wind turbines.																																											
Chance [18] Bonferroni corrections were used to reduce the possibility of spurious significant associations arising by chance as multiple statistical tests were conducted.																																											
Overall quality assessment (descriptive) [19] On the basis of the Internal Validity assessment made above, the lack of reporting of health outcomes, and the detailed critical appraisal of the study (see Table 7), this study is considered poor quality for the purpose of this review. There is a high risk of exposure misclassification (time criterion was not well-defined), uncertain sample selection bias (68% response rate), outcome misclassification (non-validated survey) and confounding. There is also the potential for recall bias (unclear if masking of study intent was effective).																																											
RESULTS																																											
Adverse effect outcomes [20] <i>Perception and annoyance outdoors (%) from wind turbine noise related to sound exposure.</i> Estimated sound pressure intervals in dB(A) <table><tr><td></td><td><30.0 n=12</td><td>30.0–32.5 n=70</td><td>32.5–35.0 n=132</td><td>35.0–37.5 n=62</td><td>37.5–40.0 n=40</td><td>>40.0 n=25</td></tr><tr><td>Do not notice</td><td>75 [51,100]</td><td>61 [50,73]</td><td>38 [30,46]</td><td>15 [3,23]</td><td>15 [4,26]</td><td>4 [19,57]</td></tr><tr><td>Notice, not annoyed</td><td>25 [1,50]</td><td>24 [14,34]</td><td>28 [20,36]</td><td>47 [34,59]</td><td>35 [20,50]</td><td>40 [19,57]</td></tr><tr><td>Slightly annoyed</td><td>0</td><td>14 [6,22]</td><td>17 [10,23]</td><td>26 [15,37]</td><td>23 [10,35]</td><td>12 [19,57]</td></tr><tr><td>Rather annoyed</td><td>0</td><td>0</td><td>10 [5,15]</td><td>6 [0,13]</td><td>8 [–1,16]^a</td><td>8 [19,57]</td></tr><tr><td>Very annoyed</td><td>0</td><td>0</td><td>8 [3,12]</td><td>6 [0,13]</td><td>20 [8,32]</td><td>36 [17,55]</td></tr></table> Note: Values are % [95% CI] unless otherwise specified. ^a Reproduced as per reported in study. This is evidently in error, as a negative percentage is not possible. The interval could plausibly be [1,16].			<30.0 n=12	30.0–32.5 n=70	32.5–35.0 n=132	35.0–37.5 n=62	37.5–40.0 n=40	>40.0 n=25	Do not notice	75 [51,100]	61 [50,73]	38 [30,46]	15 [3,23]	15 [4,26]	4 [19,57]	Notice, not annoyed	25 [1,50]	24 [14,34]	28 [20,36]	47 [34,59]	35 [20,50]	40 [19,57]	Slightly annoyed	0	14 [6,22]	17 [10,23]	26 [15,37]	23 [10,35]	12 [19,57]	Rather annoyed	0	0	10 [5,15]	6 [0,13]	8 [–1,16] ^a	8 [19,57]	Very annoyed	0	0	8 [3,12]	6 [0,13]	20 [8,32]	36 [17,55]
	<30.0 n=12	30.0–32.5 n=70	32.5–35.0 n=132	35.0–37.5 n=62	37.5–40.0 n=40	>40.0 n=25																																					
Do not notice	75 [51,100]	61 [50,73]	38 [30,46]	15 [3,23]	15 [4,26]	4 [19,57]																																					
Notice, not annoyed	25 [1,50]	24 [14,34]	28 [20,36]	47 [34,59]	35 [20,50]	40 [19,57]																																					
Slightly annoyed	0	14 [6,22]	17 [10,23]	26 [15,37]	23 [10,35]	12 [19,57]																																					
Rather annoyed	0	0	10 [5,15]	6 [0,13]	8 [–1,16] ^a	8 [19,57]																																					
Very annoyed	0	0	8 [3,12]	6 [0,13]	20 [8,32]	36 [17,55]																																					
<i>Results of multiple logistic regression analyses—impact of predictors on annoyance.</i> <table><tr><td>Variables</td><td>b</td><td>p value</td><td>Exp(b) [95% CI]</td><td>Pseudo-R²</td></tr><tr><td>1 Noise exposure</td><td>0.63</td><td><0.001</td><td>1.87 [1.47,2.38]</td><td>0.13</td></tr></table>		Variables	b	p value	Exp(b) [95% CI]	Pseudo-R ²	1 Noise exposure	0.63	<0.001	1.87 [1.47,2.38]	0.13																																
Variables	b	p value	Exp(b) [95% CI]	Pseudo-R ²																																							
1 Noise exposure	0.63	<0.001	1.87 [1.47,2.38]	0.13																																							

2	Noise exposure	0.55	<0.001	1.74 [1.29,2.34]	0.46
	Attitude to visual impact	1.62	<0.001	5.05 [3.22,7.92]	NR
3	Noise exposure	0.62	<0.001	1.86 [1.45,2.40]	0.20
	Attitude to turbines	0.56	<0.001	1.74 [1.30,2.33]	NR
4	Noise exposure	0.63	<0.001	1.88 [1.46,2.42]	0.18
	Sensitivity to noise	0.56	<0.001	1.75 [1.19,2.57]	NR
5	Noise exposure	0.55	<0.001	1.73 [1.28,2.33]	0.46
	Attitude to visual impact	1.66	<0.001	5.28 [3.26,8.56]	NR
	Attitude to turbines	-0.10	0.319	0.91 [0.64,1.28]	NR
6	Noise exposure	0.57	<0.001	1.77 [1.30,2.40]	0.47
	Attitude to visual impact	1.59	<0.001	4.88 [3.08,7.72]	NR
	Sensitivity to noise	0.22	0.344	1.25 [0.79,1.96]	NR
7	Noise exposure	0.63	<0.001	1.88 [1.45,2.45]	0.24
	Attitude to turbines	0.58	<0.001	1.78 [1.32,2.41]	NR
	Sensitivity to noise	0.59	<0.005	1.80 [1.22,2.67]	NR
8	Noise exposure	0.56	<0.001	1.76 [1.29,2.39]	0.47
	Attitude to visual impact	1.63	<0.001	5.11 [3.10,8.41]	NR
	Attitude to turbines	-0.10	0.597	0.91 [0.64,1.29]	NR
	Sensitivity to noise	0.21	0.373	1.23 [0.78,1.94]	NR
<i>Correlations between noise annoyance, estimated sound category (dB(A)) and subjective variables</i>					
	Sound category	Attitude to visual impact	Attitude to turbines	Sensitivity to noise	
Noise annoyance	0.421	0.512	0.334	0.197	
Sound category	NA	0.145	0.074	0.069	
Attitude to visual impact	NR	NA	0.568	0.194	
Attitude to turbines	NR	NR	NA	0.023	
Sensitivity to noise	NR	NR	NR	NA	
Bold text indicates statistically significant.					
<i>Verbal descriptors of sound characteristics of turbine noise for those that noticed turbine sound (n=223)</i>					
	Annoyed by specified sound character, % respondents [95% CI]	Correlation to noise annoyance			
Swishing	33 [27,40]	0.718			
Whistling	26 [18,33]	0.642			
Pulsating/throbbing	20 [14,27]	0.450			
Resounding	16 [10,23]	0.485			
Low frequency	13 [7,18]	0.292			
Scratching/squeaking	12 [6,17]	0.398			
Tonal	7 [3,12]	0.335			
Lapping	5 [1,8]	0.262			
Bold text indicates statistically significant.					
Abbreviations: NR = not reported; NA = not applicable					

Exposure group [21] See 'Adverse effect outcomes' [20].	Control group [22] NA	Measure of effect / effect size [23] 95% CI [25] See [20].	Harms (NNH) [24] 95% CI [25] NR—health outcomes not reported.
Public health importance (1–4) [26] Unable to determine according to NHMRC ranking criteria.		Relevance (1–5) [27] 5	
Comments [28] The cross-sectional study design cannot provide evidence of cause and effect, and, although exploration of potential sources of confounding was done, there were some potential confounders that were not addressed. Results may be affected by recall bias, although attempts were made to mask study intent. Health outcomes were not reported. The study has limited capacity to inform the assessment of wind turbine noise as a cause of adverse health effects.			

ARTICLE DETAILS		
Reference [1] Pedersen , E & Persson Waye, K 2007 , 'Wind turbine noise, annoyance and self-reported health and well-being in different living environments', <i>Occupational and Environmental Medicine</i> , vol. 64, no. 7, pp. 480–486.		
Affiliation/source of funds [2] Occupational and Environmental Medicine, Sahlgrenska Academy, Göteborg University, Göteborg, Sweden. Funded through grant P2005-04699 by the Swedish Energy Agency.		
Study design [3] Cross-sectional study.	Level of evidence [4] IV	Location/setting [5] Seven wind turbine areas in Sweden representing different landscapes with regard to terrain and urbanisation. Proximity/distance: Mean, 780±233 m
Exposure description [6] Wind farm details: Wind turbines with nominal power >500 kW (authors reported that some turbines with nominal power <500 kW were included for analysis). Tower height >65 m. Specific exposure details: Sound pressure levels (SPL) collected from reports by consultancies, manufacturers and local authorities, or, where data were unavailable, older/smaller machines. Noise emission was estimated outside each respondent's residence. The standard model of sound propagation proposed by the Swedish Environmental Protection Agency was used to estimate A-weighted SPL in decibels (dB), based on downwind conditions ($\pm 45^\circ$) with wind speed 8 m/s at height 10 m. SPL divided into 5 categories: <32.5, 32.5–35.0, 35.0–37.5, 37.5–40.0 and >40.0 dB(A). Turbine area types included Areas I–IV where ground was rocky and/or the altitude of the base of the wind turbines varied; and Areas V–VII, which were flat. Areas I, IV and VII were classified as suburban, Areas II, III, V and VI as rural. Sample size [7]		Control(s) description [8] No non-exposed groups were included in the study. A distribution of participant characteristics across different environmental exposures was included (see 'Specific exposure details'); however, these classifications do not coincide with the different sound pressure levels considered and no analysis based on these subgroups was presented. Sample size [9] See 'Population characteristics'.

Respondents, n=754; non-respondents, n=555; response rate = 58%.								
Population characteristics [10]								
Exposure group:								
	I	II	III	IV	V	VI	VII	Total
Sample, n	396	24	23	221	148	112	385	1309
Respondents, n	206	16	12	141	87	70	222	754
Age, years	52±15	51±18	54±15	52±14	49±16	49±15	51±15	51±15
Sex, % male	40	53	58	47	48	38	46	44
Occupation,								
% employed	54	33	58	57	61	58	62	58
% retired	28	53	33	24	22	21	23	25
Housing type,								
% detached	70	93	100	70	89	93	82	79
Time in current dwelling, years	14±14	16±10	16±15	15±13	15±15	15±16	16±12	15±13
Distance to nearest turbine, m	862±184	636±254	670±284	812±151	834±266	1014±245	605±160	780±233
Sound pressure level, dB(A)	31.4±2.3	38.2±4.7	33.8±4.5	33.2±1.4	34.6±3.2	31.9±2.3	35.0±2.9	33.4±3.0
Visual angle, degrees	3.5±0.9	10.8±3.9	8.4±4.3	2.5±0.4	2.7±1.3	3.6±1.7	3.8±0.8	3.5±1.7
Respondents with ≥1 turbine visible, %	64	75	67	60	91	88	71	71
Respondents noise sensitive, %	54	50	42	59	39	56	48	51
Self-rated health, % chronic disease	36	33	67	35	21	26	32	33
Self-rated sleep, % not good	9	0	0	6	5	4	5	6
Values are mean±SD unless otherwise indicated								
Length of follow-up [11]				Outcome(s) measured and/or analyses undertaken [12]				
NA (cross-sectional design).				No data from the subgroup analysis based on different categories of noise levels could be extracted; however, a later study (Pedersen 2011) contains data on relevant endpoints for the same study population considered here.				
				The outcomes reported in this study were: perception of noise and annoyance with noise.				

INTERNAL VALIDITY Confounding subscale [13] Comment on sources of confounding: Analysis adjusted for age and sex and multiple other factors (see 'Results') but it is unknown if confounding due to economic benefit occurred. Findings could be partly due to differences between rural and urban areas in terms of background noise, which is not an exposure of interest. Other plausible confounders not addressed were: chronic disease and risk factors for chronic disease, occupation and education. Bias subscale [14] Comment on sources of bias: Study intent was masked, but unclear how effectively and so whether recall bias has affected results.	EXTERNAL VALIDITY Generalisability [15] Overall mean distance from wind turbines ~800 m; potential for differences between the total population living near the included wind farms and those that responded to questionnaire (58% response rate). Applicability [16] Uncertain whether the population characteristics and the wind turbine exposures of those living near Swedish wind farms are comparable to populations near wind farms in Australia.									
Reporting subscale [17] Comment on quality of reporting: Good reporting of responder demographics according to sound exposure groups, although baseline health was not considered (cross-sectional design), nor the characteristics of non-responders. The study did not report on economic benefits from wind turbines.										
Chance [18] There was the possibility of spurious significant associations because of the multiple statistical analyses undertaken.										
Overall quality assessment (descriptive) [19] There was good reporting of study characteristics and adjustment for potential confounders, and attempts to reduce recall bias through masking study intent. There are still concerns regarding plausible confounders not being controlled. Health outcomes were not reported. There was the possibility of spurious significant associations with annoyance because of the multiple statistical analyses undertaken. Unclear whether there is sample selection bias, given the moderate response rate. High risk of outcome misclassification as the survey tool was not validated. The study was of poor quality for the purpose of this review. For further critical appraisal of the study, see Table 7.										
RESULTS										
Adverse effect outcomes [20] Association between perception of noise from wind turbines, dependent variable 'Do not notice' (n=457) or 'Notice' (n=307) and variables hypothesised to influence perception. <table><tr><th>Sound pressure, dB(A)</th><th>Other variables hypothesised to influence perception</th><th></th></tr><tr><td></td><th>Variable of interest (ref; tested category)^a</th><th>OR [95% CI]</th></tr><tr><td>1.3 [1.26,1.41]</td><td>Age (years; +1 year)</td><td>1.0 [0.99,1.01]</td></tr></table>		Sound pressure, dB(A)	Other variables hypothesised to influence perception			Variable of interest (ref; tested category) ^a	OR [95% CI]	1.3 [1.26,1.41]	Age (years; +1 year)	1.0 [0.99,1.01]
Sound pressure, dB(A)	Other variables hypothesised to influence perception									
	Variable of interest (ref; tested category) ^a	OR [95% CI]								
1.3 [1.26,1.41]	Age (years; +1 year)	1.0 [0.99,1.01]								

1.3 [1.26,1.41]	Sex (male; female)	1.0 [0.83,1.16]
1.3 [1.26,1.41]	Employment (employed; not employed)	0.7 [0.48,0.91]
1.3 [1.26,1.41]	Housing (apartment; detached house)	1.6 [1.04,2.33]
1.3 [1.24,1.40]	Terrain (complex; flat)	1.1 [0.81,1.56]
1.3 [1.25,1.41]	Urbanisation (suburban; rural)	1.8 [1.25,2.51]
1.3 [1.24,1.41]	Terrain and urbanisation	
	Suburban & flat ground (n=222)	1.0
	Suburban & complex ground (n=347)	1.0 [0.65,1.48]
	Rural & flat ground (n=157)	1.6 [1.01,2.53]
	Rural & complex ground (n=28)	4.8 [1.65,13.72]
1.3 [1.22,1.38]	Subjective background noise (not quiet; quiet)	1.8 [1.25,2.51]
1.3 [1.22,1.37]	Visibility (no; yes)	2.2 [1.47,3.18]
Model 1 ^{bc} (Hosmer and Lemshow test: 0.703)		
	Sound pressure level, dB(A)	1.3 [1.21,1.39]
	Employment (employed; not employed)	0.6 [0.40,0.83]
	Terrain (complex; flat)	0.6 [0.38,0.97]
	Urbanisation (suburban; rural)	2.3 [1.34,3.88]
	Subjective background noise (not quiet; quiet)	2.6 [1.72,3.95]
	Visibility (no; yes)	2.3 [1.51,3.47]
Model 2 ^{bc} (Hosmer and Lemshow test: 0.703)		
	Sound pressure level, dB(A)	1.3 [1.21,1.39]
	Employment (employed; not employed)	0.6 [0.40,0.83]
	Terrain and urbanisation	
	Suburban & flat ground (n=222)	1.0
	Suburban & complex ground (n=347)	1.6 [1.03,2.63]
	Rural & flat ground (n=157)	2.2 [1.34,3.89]
	Rural & complex ground (n=28)	13.8 [4.24,45.15]
	Subjective background noise (not quiet; quiet)	2.6 [1.72,3.95]
	Visibility (no; yes)	2.3 [1.51,3.47]
^a Variables were entered one by one into a binary logistic regression, always keeping sound pressure level in the regression as the main factor of importance for perception. ^b Models 1 and 2 comprise several variables simultaneously entered into a binary logistic regression. ^c Adjusted for age and sex.		
<i>Association between annoyance with noise from wind turbines, dependent variable 'Not annoyed' (n=723) or 'Annoyed' (n=31) and variables hypothesised to influence annoyance.</i>		
<u>Sound pressure, dB(A)</u>	<u>Other variables hypothesised to influence annoyance</u>	
	Variable of interest (ref; tested category) ^a	OR [95% CI]
1.1 [1.03,1.27]	Age (years; +1 year)	1.0 [0.99,1.04]
1.1 [1.02,1.26]	Sex (male; female)	0.9 [0.50,1.64]
1.1 [1.01,1.25]	Employment (employed; not employed)	1.3 [0.61,2.60]
1.1 [1.01,1.25]	Housing (apartment; detached house)	2.5 [0.75,8.40]
1.1 [1.01,1.25]	Length of time in current dwelling (years; +1 year)	1.0 [1.00,1.05]
1.1 [1.02,1.26]	Terrain (complex; flat)	0.8 [0.39,1.76]
1.1 [0.99,1.21]	Urbanisation (suburban; rural)	3.8 [1.80,7.83]
1.1 [0.98,1.23]	Terrain and urbanisation	
	Suburban & flat ground (n=222)	1.0
	Suburban & complex ground (n=347)	2.1 [0.63, 7.28]
	Rural & flat ground (n=157)	5.2 [1.62, 16.65]
	Rural & complex ground (n=28)	10.1 [2.46, 41.61]
1.1 [0.91,1.21]	Subjective background noise (not quiet; quiet)	3.6 [1.21, 10.67]
1.1 [1.02,1.26]	Noise sensitivity (not sensitive; sensitive)	2.5 [1.14,5.63]

1.1 [1.00,1.25]	General attitude to turbines (not negative; negative)	13.4 [6.03,29.59]	
1.1 [1.00,1.25]	Attitude to visual impact of turbines (not negative; negative)	14.4 [6.37,32.44]	
1.1 [1.01,1.25]	'I live in a place where I can restore myself and gain strength' (disagree; agree)	0.3 [0.13,0.74]	
1.1 [1.01,1.25]	'I have renovated my dwelling' (no; yes)	2.6 [1.03,6.33]	
1.0 [0.88,1.16]	Vertical visual angle (degrees; +1 degree)	1.2 [1.03,1.42]	
1.1 [0.97,1.21]	Visibility (no; yes)	10.9 [1.46,81.92]	
^a Variables were entered one by one into a binary logistic regression, always keeping sound pressure level in the regression as the main factor of importance for perception. Abbreviations: OR = odds ratio			
Exposure group [21] As per 'Adverse effect outcomes' [20].	Control group [22] NA	Measure of effect / effect size [23] 95% CI [25] See [20].	Harms (NNH) [24] 95% CI [25] Health effects were not reported.
Public health importance (1–4) [26] Cannot be determined according to NHMRC ranking criteria.		Relevance (1–5) [27] 5	
Comments [28] Health outcomes were not reported. Annoyance could lead to stress which is a potential mediating factor in adverse health but stress was not assessed. Cross-sectional design does not permit conclusions regarding cause and effect. Good attempt at controlling for confounding. The study has limited capacity to inform the assessment of wind turbine noise as a cause of adverse health effects.			

ARTICLE DETAILS		
Reference [1] Pedersen, E & Larsman, P 2008 , 'The impact of visual factors on noise annoyance among people living in the vicinity of wind turbines', <i>Journal of Environmental Psychology</i> , vol. 28, no. 4, pp. 379–389.		
Affiliation/source of funds [2] Occupational and Environmental Medicine, Sahlgrenska Academy, Göteborg University, Sweden; Department of Psychology, Göteborg University, Sweden. Funded through grant P22509-1 by the Swedish Energy Agency.		
Study design [3] Analysis based on two cross-sectional studies: 1. Pedersen, E & Persson Waye, KP 2004, 'Perception and annoyance due to wind turbine noise: a dose–response relationship', <i>Journal of the Acoustical Society of America</i> , vol. 116, no. 6, pp. 3460–3470. 2. Pedersen, E & Persson Waye, K 2007, 'Wind turbine noise, annoyance and self-reported health and well-being in different living environments', <i>Occupational and Environmental Medicine</i> , vol. 64, no. 7, pp. 480–486.	Level of evidence [4] IV	Location/setting [5] 12 geographical areas in southern Sweden that differed with regard to terrain (flat or hilly/rocky) and degree of urbanisation (built-up or rural). Proximity/distance: Pedersen & Persson Waye (2004): Distance from dwelling of respondent to nearest turbine, range = 150–1199 m. Pedersen & Persson Waye (2007): Mean, 780±233 m.
Exposure description [6] Wind farm details: <i>Pedersen & Persson Waye (2004)</i> 14 towers within the study areas had a power output of 600–650 kW, 2 towers had outputs of 500 kW and 150 kW. Tower height, range = 47–50 m. Turbine make: 13 WindWorld, 2 Enercon, 1 Vestas. <i>Pedersen & Persson Waye (2007)</i> Wind turbines with nominal power >500 kW (authors reported that some turbines with nominal power <500 kW were included for analysis). Specific exposure details: <i>Pedersen & Persson Waye (2004)</i>	Control(s) description[8] No non-exposed groups were included in the study. Outcomes were measured across different types of environmental exposure (see 'Specific exposure details'). Sample size [9] See 'Population characteristics'.	

Estimated A-weighted (dB(A)) sound levels were based on sound propagation models calculating levels at each respondent's dwelling, and these levels were grouped into 6 categories as shown at 'Population characteristics'.

Pedersen & Persson Waye (2007)

Sound power levels collected from reports by consultancies, manufacturers and local authorities, or, where data were unavailable, older/smaller machines. Noise emission was measured outside each respondent's residence. The standard model of sound propagation proposed by the Swedish Environmental Protection Agency was used to estimate as equivalent continuous A-weighted sound pressure level in decibels (dB), based on downwind conditions ($\pm 45^\circ$) with wind speed 8 m/s at height 10 m.

Turbine area types included Areas I–IV, where ground was rocky and/or the altitude of the base of the wind turbines varied; and Areas V–VII, which were flat. Areas I, IV and VII were classified as suburban, Areas II, III, V and VI as rural.

Sample size [7]

Pedersen & Persson Waye (2004)

Total = 513; respondents, n=351; non-respondents, n=162; response rate 68%.

Pedersen & Persson Waye (2007)

Total = 1309; respondents, n=754; non-respondents, n=555; response rate 58%.

Population characteristics [10]

Exposure group:

In both individual studies, demographic characteristics were presented across different levels of sound pressure (Pedersen & Persson Waye 2004) and dwelling/topographic features (Pedersen & Persson Waye 2007). The results of Pedersen (2008) were not reported according to the categories of exposure examined in the individual studies.

Pedersen & Persson Waye (2004)

	Estimated A-weighted sound pressure intervals in dB(A) ^a						
	<30.0	30.0–32.5	32.5–35.0	35.0–37.5	37.5–40.0	>40.0	Total
Study sample, n	25	103	200	100	53	32	513
Study population, n	15	71	137	63	40	25	351
Response rate, %	60	68.9	68.5	63	75.5	78.1	68.4
Age, mean $\pm$ SD, years	46 $\pm$ 13.3	47 $\pm$ 13.3	47 $\pm$ 14.3	50 $\pm$ 14.6	48 $\pm$ 13.1	48 $\pm$ 14.3	48 $\pm$ 14.0
Sex, % male	27	35	39	50	50	48	42

Residence, detached house/farm %	100	83	61	100	97	96	81	
Occupation, % employed	67	59	58	53	69	67	60	
Sensitive to noise, %	62	44	49	53	58	50	50	
Negative toward turbines, %	8	10	11	18	20	8	13	
Negative to turbine visual impact, %	43	33	38	41	40	58	40	
Long-term illness, %	20	29	28	16	30	24	26	
^a These are the intervals as reported by the authors. Note that the intervals are not mutually exclusive. For further details regarding the utility/relevance of results included in this paper, see ‘Outcomes measured’.								
Abbreviations: SD = standard deviation								
<i>Pedersen & Persson Waye (2007)</i>								
	I	II	III	IV	V	VI	VII	Total
Sample, n	396	24	23	221	148	112	385	1309
Respondents, n	206	16	12	141	87	70	222	754
Age, years	52±15	51±18	54±15	52±14	49±16	49±15	51±15	51±15
Sex, % male	40	53	58	47	48	38	46	44
Occupation, % employed	54	33	58	57	61	58	62	58
% retired	28	53	33	24	22	21	23	25
Housing type, % detached	70	93	100	70	89	93	82	79
Time in current dwelling, years	14±14	16±10	16±15	15±13	15±15	15±16	16±12	15±13
Distance to nearest turbine, m	862±184	636±254	670±284	812±151	834±266	1014±245	605±160	780±233
Sound pressure level, dB(A)	31.4±2.3	38.2±4.7	33.8±4.5	33.2±1.4	34.6±3.2	31.9±2.3	35.0±2.9	33.4±3.0
Visual angle, degrees	3.5±0.9	10.8±3.9	8.4±4.3	2.5±0.4	2.7±1.3	3.6±1.7	3.8±0.8	3.5±1.7
Respondents with ≥1 turbine visible, %	64	75	67	60	91	88	71	71
Respondents noise sensitive, %	54	50	42	59	39	56	48	51
Self-rated health, % chronic disease	36	33	67	35	21	26	32	33
Self-rated sleep, % not good	9	0	0	6	5	4	5	6
Values are mean±SD unless otherwise indicated								
Length of follow-up [11]				Outcome(s) measured and/or analyses undertaken [12]				
NA (cross-sectional study).				Three constructs of annoyance (due to noise, visual				

			attitude and general attitude). No health outcomes measured.			
INTERNAL VALIDITY			EXTERNAL VALIDITY			
Confounding subscale [13] <i>Comment on sources of confounding:</i> Confounding is a risk as the possibility of different distributions of economic benefit among the sound exposure groups was not analysed.			Generalisability [15] For both studies (i.e. Pedersen and Persson Waye 2004, 2007), distance from wind turbines did not exceed 1.2 km; potential for differences between the total population living near the included wind farms and those that responded to questionnaire.			
Bias subscale [14] <i>Comment on sources of bias:</i> Recall bias cannot be excluded, although masking of study intent was attempted in both studies.			Applicability [16] Uncertain whether the population characteristics and the wind turbine exposures of those living near selected Swedish wind farms are comparable to populations near wind farms in Australia.			
Reporting subscale [17] <i>Comment on quality of reporting:</i> Poor reporting of participant characteristics and background data for non-respondents was not provided. The demographic data provided in this table have been extracted from the studies detailed above, which form the basis of the re-analysis of data in Pedersen (2008).						
Chance [18] This study is a re-analysis of the original studies conducted by Pedersen and Persson Waye as published in 2004 and 2007, and it is possible that spurious significant associations arose because of the multiple statistical analyses undertaken.						
Overall quality assessment (descriptive) [19] For further critical appraisal of the study, see Table 7. Detailed discussion of selection process. There is a high risk of exposure misclassification (time criterion was not well-defined), outcome misclassification (non-validated surveys), confounding and statistically significant associations arising by chance. There is also the potential for recall bias (unclear if masking of study intent was effective) and an uncertain risk of sample selection bias.						
RESULTS						
Adverse effect outcomes [20]						
Regression weights	Exposure groups				Difference between groups^a	
	Estimate	p value	Estimate	p value	Difference	p value
	At least one turbine visible group		No turbines visible group			
Noise level → noise annoyance	0.35	<0.001	0.29	<0.01	0.06	<0.001

Visual attitude → noise annoyance	0.59	<0.001	0.57	<0.05	0.32	<0.05
General attitude → noise annoyance	–0.06	0.375	–0.35	0.169	NR	NR
	Flat terrain		Rocky terrain			
Noise level → noise annoyance	0.32	<0.001	0.29	<0.001	–0.02	0.201
Visual attitude → noise annoyance	0.71	<0.001	0.57	0.445	NR	NR
General attitude → noise annoyance	–0.16	0.058	–0.35	0.191	NR	NR
	Built-up area		Rural area			
Noise level → noise annoyance	0.42	<0.001	0.35	<0.001	0.01	0.418
Visual attitude → noise annoyance	0.58	<0.001	0.57	<0.001	–0.03	0.873
General attitude → noise annoyance	–0.15	0.076	–0.02	0.867	NR	NR
^a Only calculated if the estimates were statistically significant.						
Annoyance due to noise:						
• Flat vs rocky terrain: noise levels had an effect on annoyance both for respondents living in both flat terrain and hilly/rocky terrain. • Built-up vs rural area: noise levels had an effect on annoyance both for respondents living in both built-up areas and rural areas. • Visibility of wind turbines from dwelling vs non-visibility: noise levels had an effect on annoyance for both groups, but the level of annoyance appeared stronger for the ‘visibility of wind turbines’ group.						
<i>Regression coefficients from multiple linear regressions with the dependent variable ‘response to wind turbine noise’.</i>						
	A-weighted sound pressure level		Revised vertical visual angle			
	<i>B</i> [95% CI]				<i>B</i> [95%CI]	
	<i>R</i> ²					
Wing turbines visible	0.12	[0.099,0.143]			0.01	[0.009,0.020]
	0.04					
Turbines not visible	0.06	[0.001,0.025]			0.00	[–0.002,0.008]
	0.14					
Flat terrain	0.13	[0.102,0.152]			0.03	[0.023,0.040]
	0.15					
Hilly/rocky terrain	0.13	[0.104,0.161]			0.00	[–0.001,0.008]
	0.20					
Built-up area	0.13	[0.103,0.150]			0.00	[–0.007,0.013]
	0.14					
Rural area	0.11	[0.078,0.145]			0.01	[0.003,0.016]
	0.14					

Exposure group [21] See 'Adverse effect outcomes [20].	Control group [22] NA	Measure of effect / effect size [23] 95% CI [25] See [20].	Harms (NNH) [24] 95% CI [25] Health effects not reported.
Public health importance (1–4) [26] Cannot be determined according to NHMRC ranking criteria.		Relevance (1–5) [27] 5	
Comments [28] Cross-sectional design cannot provide evidence of cause and effect. Health outcomes were not measured. The effects of visual and attitude factors on annoyance were considered; however, whether annoyance leads to adverse health outcomes has not been established. Economic benefit from wind turbines may influence annoyance, but this was not investigated. The study has limited capacity to inform the assessment of wind turbine noise as a cause of adverse health effects.			

ARTICLE DETAILS		
Reference [1] Pedersen, E 2011 , 'Health aspects associated with wind turbine noise: results from three field studies', <i>Noise Control Engineering Journal</i> , vol. 59, no. 1, pp. 47–53. ^a See individual studies for additional details not provided here: 1. Pedersen, E & Waye, KP 2004, 'Perception and annoyance due to wind turbine noise: a dose–response relationship', <i>Journal of the Acoustical Society of America</i> , vol. 116, no. 6, pp. 3460–3470. 2. Pedersen, E & Persson Waye, K 2007, 'Wind turbine noise, annoyance and self-reported health and well-being in different living environments', <i>Occupational and Environmental Medicine</i> , vol. 64, no. 7, pp. 480–486. 3. Pedersen, E, van den Berg, F, Bakker, R & Bouma, J 2009, 'Response to noise from modern wind farms in The Netherlands', <i>Journal of the Acoustical Society of America</i> , vol. 126, no. 2, pp. 634–643.		
Affiliation/source of funds [2] ^a		
Study design [3] Cross-sectional study.	Level of evidence [4] IV	Location/setting [5] Sweden; The Netherlands. Proximity/distance: ^a
Exposure description [6] Wind farm details: ^a Specific exposure details: ^a Sample size [7] Total respondents with complete data across three studies, n=1661 (total number who received survey not reported ^a).		Control(s) description [8] No non-exposed groups were included in the study. Responder characteristics across different types of environmental and/or noise exposure were reported; however, no analysis based on these subgroups was presented in Pedersen 2011 or the individual studies used for the analysis. Sample size [9] See ‘Population characteristics’.
Population characteristics [10] Exposure group: Not reported. ^a		

Length of follow-up [11] NA (cross-sectional study)	Outcome(s) measured and/or analyses undertaken [12] (a) association between A-weighted sound pressure levels and self-reported health symptoms/responses including annoyance outdoors and indoors, sleep interruption, chronic disease (unspecified), diabetes, hypertension, cardiovascular disease, tinnitus, impaired hearing, headache, undue tiredness, tension and stress, and irritability; (b) association between annoyance outdoors due to wind turbine noise and the self-reported health symptoms listed at (a); (c) association between annoyance indoors due to wind turbine noise and self-reported health symptoms listed at (a).
INTERNAL VALIDITY Confounding subscale [13] <i>Comment on sources of confounding:</i> Poor reporting of participant characteristics. No baseline health data were provided. Adjustment for age, sex and economic benefit was performed in NL-07. Adjustment for age and sex in SWE-00 and SWE-05 results. Other plausible confounders not addressed ie chronic disease and risk factors for chronic disease, occupation, education, employment, terrain, urbanisation, background noise, and turbine visibility. Bias subscale [14] <i>Comment on sources of bias:</i> Sample selection bias is more likely with response rates below 70%, as was the case for all three of the studies. Self-report of outcomes so possibility of outcome misclassification. Uncertain success of masking of study intent, so there is potential for recall bias.	EXTERNAL VALIDITY Generalisability [15] Potential for differences between the total population living near the included wind farms and those that responded to questionnaire. Applicability [16] Unknown whether the population characteristics and the wind turbine exposures of those living near wind farms in Sweden and The Netherlands are comparable to those living near wind farms in Australia.
Reporting subscale [17] <i>Comment on quality of reporting:</i> Fair, as most aspects were addressed adequately, with the exception of baseline demographic characteristics.	

Chance [18]

There was the possibility of spurious significant associations because of the multiple statistical analyses undertaken.

Overall quality assessment (descriptive) [19]

On the basis of the Internal Validity assessment made on each of the individual studies, and the detailed critical appraisal of the studies given in Table 7, this re-analysis is considered poor quality for the purpose of this review.

An individual quality assessment of the studies is given above.

Good attempt to determine consistency of results between studies.

RESULTS

Adverse effect outcomes [20]

Association between A-weighted sound pressure levels (independent, continuous variable) and variables measuring response and/or effect (dependent, binary variable) tested with logistic regression.

	SWE-00 ^a n=319–333 ^c	Study group SWE-05 ^a n=720–744 ^c	NL-07 ^b n=639–678 ^c
Self-reported symptoms			
Annoyance outdoors	1.24 [1.13,1.36]^d	1.14 [1.03,1.27]	1.18 [1.12,1.24]
Annoyance indoors	1.38 [1.20,1.57]	1.42 [1.17,1.71]	1.20 [1.13,1.27]
Sleep interruption	1.12 [1.03,1.22]	0.97 [0.90,1.05]	1.03 [1.00,1.07]
Chronic disease	0.97 [0.89,1.05]	1.01 [0.96,1.07]	0.98 [0.95,1.01]
Diabetes	0.96 [0.79,1.16]	1.13 [1.00,1.27]	1.00 [0.92,1.03]
High blood pressure	1.03 [0.90,1.17]	1.05 [0.97,1.13]	1.01 [0.96,1.06]
Cardiovascular disease	0.87 [0.68,1.10]	1.00 [0.88,1.13]	0.98 [0.91,1.05]
Tinnitus	1.25 [1.03,1.50]	0.97 [0.88,1.07]	0.94 [0.85,1.04]
Impaired hearing	1.09 [0.93,1.27]	1.05 [0.95,1.15]	1.01 [0.94,1.10]
Headache	0.95 [0.88,1.02]	1.04 [0.99,1.10]	1.01 [0.98,1.04]
Undue tiredness	0.95 [0.88,1.02]	0.98 [0.93,1.03]	1.02 [0.99,1.05]
Tense and stressed	1.02 [0.94,1.10]	1.00 [0.95,1.05]	1.01 [0.98,1.04]
Irritable	1.03 [0.96,1.11]	1.00 [0.96,1.06]	1.01 [0.98,1.04]

Bold text indicates statistically significant association.

^a Adjusted for age and sex.

^b Adjusted for age, sex and economic benefits.

^c Range of number of respondents in the analyses. Differences in number of respondents are due to missing cases, that is, the respondents not answering single questions in the questionnaire.

^d [95% CI]

Association between annoyance outdoors due to wind turbine noise (independent, continuous variable) and variables measuring response and/or effect (dependent, binary variable) tested with logistic regression.

	SWE-00 ^a n=319–333 ^c	Study group SWE-05 ^a n=720–744 ^c	NL-07 ^b n=658–672 ^c
Self-reported symptoms			
Sleep interruption	2.26 [1.76,2.90]^d	1.71 [1.35,2.17]	1.78 [1.49,2.14]
Chronic disease	0.90 [0.71,1.08]	0.90 [0.74,1.26]	0.98 [0.81,1.19]
Diabetes	0.69 [0.37,1.31]	0.71 [0.40,1.28]	1.70 [1.14,2.56]

High blood pressure	0.82 [0.55,1.22]	1.10 [0.84,1.45]	0.86 [0.64,1.17]
Cardiovascular disease	1.07 [0.58,1.98]	1.00 [0.64,1.55]	0.95 [0.65,1.38]
Tinnitus	1.55 [0.95,2.53]	0.88 [0.60,0.98]	0.82 [0.45,1.48]
Impaired hearing	1.03 [0.96,1.19]	0.78 [0.51,1.21]	1.13 [0.76,1.67]
Headache	1.24 [1.01,1.51]	1.04 [0.86,1.26]	1.25 [1.04,1.50]
Undue tiredness	1.22 [1.00,1.49]	1.12 [0.93,1.35]	1.10 [0.93,1.31]
Tense and stressed	1.25 [1.00,1.56]	1.22 [1.00,1.50]	1.27 [1.07,1.50]
Irritable	1.36 [1.10,1.69]	1.22 [1.00,1.49]	1.27 [1.07,1.50]

Bold text indicates statistically significant association.

^a Adjusted for age, sex, and A-weighted sound pressure levels.

^b Adjusted for age, sex, A-weighted sound pressure levels, and economic benefits.

^c Range of number of respondents in the analyses. Differences in number of respondents are due to missing cases, that is, the respondents not answering single questions in the questionnaire.

^d [95% CI]

Association between annoyance indoors due to wind turbine noise (independent, continuous variable) and variables measuring response and/or effect (dependent, binary variable) tested with logistic regression.

	SWE-00 ^a n=318–331 ^c	Study group SWE-05 ^a n=719–743 ^c	NL-07 ^b n=624–659 ^c
Self-reported symptoms			
Sleep interruption	2.62 [1.90, 3.61]^d	2.58 [1.79, 3.71]	2.03 [1.66, 2.47]
Chronic disease	0.93 [0.69, 1.25]	0.94 [0.68, 1.31]	1.05 [0.09, 1.28]
Diabetes	0.73 [0.30, 1.75]	0.59 [0.22, 1.59]	1.62 [1.10, 2.40]
High blood pressure	0.07 [0.36, 1.19] ^e	0.85 [0.52, 1.38]	0.83 [0.59, 1.16]
Cardiovascular disease	0.99 [0.46, 2.17]	0.97 [0.49, 1.94]	0.76 [0.47, 1.22]
Tinnitus	1.25 [0.77, 2.05]	0.57 [0.24, 1.33]	0.67 [0.28, 1.57]
Impaired hearing	1.14 [0.72, 1.79]	0.56 [0.24, 1.32]	1.20 [0.80, 1.80]
Headache	1.07 [0.83, 1.37]	1.11 [0.81, 1.52]	1.28 [1.06, 1.54]
Undue tiredness	1.36 [1.05, 1.77]	1.00 [0.95, 1.80]	1.15 [0.96, 1.37]
Tense and stressed	1.03 [0.79, 1.35]	1.07 [0.77, 1.48]	1.24 [1.04, 1.48]
Irritable	1.22 [0.93, 1.61]	1.23 [0.80, 1.72]	1.26 [1.06, 1.50]

Bold text indicates statistically significant association.

^a Adjusted for age, sex, and A-weighted sound pressure levels.

^b Adjusted for age, sex, A-weighted sound pressure levels, and economic benefits.

^c Range of number of respondents in the analyses. Differences in number of respondents are due to missing cases, that is, the respondents not answering single questions in the questionnaire.

^d [95% CI].

^e OR and 95%CI as printed in Pedersen 2011.

Exposure group [21]	Control group [22]	Measure of effect / effect size [23]	Harms (NNH) [24]
See 'Adverse effect outcomes' [20].	NA	95% CI [25] See [20].	95% CI [25] See [20].

Public health importance (1–4) [26] The majority of the statistically significant results identified were health-related effects but not health effects <i>per se</i>. Tinnitus, diabetes and headache are health outcomes and could possibly be ranked 2 according to NHMRC criteria (tinnitus reduced in one study, while diabetes and headache increased each in one study). However, these results were not replicated in other studies.	Relevance (1–5) [27] 1
Comments [28] Cross-sectional design cannot provide evidence of cause and effect. The majority of the self-reported health outcomes are patient-relevant. Annoyance is a subjective outcome of uncertain significance to health. Good attempt at controlling for confounding in individual studies, although several possible confounders were not measured or adjusted for. The authors comment appropriately on the possibility of statistical associations arising by chance (i.e. through multiple statistical testing) and so were cautious in attributing an association unless it independently occurred in all three studies. The study has limited capacity to inform the assessment of wind turbine noise as a cause of adverse health effects.	

Abbreviations: NR = not reported; NC = not calculable

Explanatory notes

[1] Full reference citation details

[2] Details of how the study was funded or other relevant affiliations of the authors (designed to expose potential conflicts of interest)

[3] The study type (e.g. RCT, case-control study, cohort study), with additional detail where relevant

[4] As per the NHMRC levels of evidence in Merlin, Weston and Tooher (2009) or NHMRC (2009)

[5] Country/setting (e.g. detail on location in rural area, wind farm distance/proximity to study participants and turbine visibility)

[6] Detail on the exposure, including the type of wind farm, number of turbines, design/model of turbines, age of turbines, when construction of the wind farm was completed, community participation in decision making etc. Detail is required on the specific exposures—audible noise, infrasound/inaudible noise, shadow flicker, electromagnetic radiation, e.g. dose/level of exposure

[7] Number of participants enrolled in the exposure group

[8] The type of control used. There may be more than one comparator (e.g. no wind farm (no exposure), different type of wind farm)

[9] Number of participants enrolled in the comparison/control group(s)

[10] Any factors that may confound/influence the results and/or the external validity (see below) of the results (e.g. age, sex, comorbidities, existing medications, socioeconomic status, baseline attitudes to wind farm siting, education level, occupation (e.g. shift work), psychosocial stressors, financial implications of wind farm siting)

[11] Length of follow-up of the participants

[12] The outcomes studied (all adverse health effects mentioned in the study)

INTERNAL VALIDITY (QUALITY ASSESSMENT)

[13] Report outcomes of use of modified Downs & Black checklist for the Confounding subscale. Comment on likelihood of confounding having affected the results and justify

[14] Report outcomes of use of modified Downs & Black checklist for the Bias subscale. Comment on likelihood of bias having affected the results and justify

EXTERNAL VALIDITY

[15] Report outcomes of use of modified Downs & Black checklist for the External Validity subscale. Comment on generalisability of the study results and justify; that is, are the participants in the study so different from the target population for the NHMRC recommendation that the results may not be generalisable to them?

[16] Is the exposure in the study so different from the exposures likely to occur in Australia that the results may not be applicable?

[17] Report outcomes of use of modified Downs & Black checklist for the Reporting subscale. Comment on appropriateness of reporting in the study

[18] When assessing the role of chance, note the use of multiple statistical testing and data dredging, which may result in spurious statistically significant results

[19] Describe your assessment (in words) of the overall quality of the study. Is the study quality good enough that you have confidence in the results?

RESULTS

Allowing one row for each relevant outcome, enter the following data from the results of the study:

[20] The outcome relevant for this entry in the database (Note: more than one table may be required if there are several outcomes relevant to different questions)

[21] For binary outcomes, show numbers of participants with the outcome. For continuous outcomes, show means $\pm$ standard deviations; or medians and interquartile ranges

[22] For binary outcomes, show numbers of participants with the outcome. For continuous outcomes, show means $\pm$ standard deviations; or medians and interquartile ranges. Add number of columns as needed (e.g. 3-arm trials)

[23] Absolute and relative measures of effect and measure of variability, for example risk differences (absolute risk reduction or absolute risk increase), mean differences, relative risk, odds ratio

[24] A measure of harm, when the exposure increases the risk of specified adverse outcomes. The number needed to expose to harm (NNH) = the number of participants who, if they receive the exposure, would lead to one additional person being harmed compared with participants who are not exposed; calculated as $1/\text{absolute risk increase}$, rounded up to the next highest whole number

[25] 95% confidence interval (CI) for all measures, if available; otherwise, use p value (be explicit on what comparison the p value relates to)

[26] Insert the appropriate rating from the scale provided at p. 23 of the NHMRC toolkit publication: *How to use the evidence: assessment and application of scientific evidence*

[27] Insert the appropriate rating from the scale provided at p. 28 of the NHMRC toolkit publication: *How to use the evidence: assessment and application of scientific evidence*

[28] Add your overall comments regarding the interpretation or implications of this study.

APPENDIX C – EXCLUDED ARTICLES

Study design unsuitable

Pedersen, E, Hallberg, LRM & Waye, KP 2007, 'Living in the vicinity of wind turbines: a grounded theory study', *Qualitative Research in Psychology* vol. 4, no. 1–2, pp. 63.

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Study outcome(s) unsuitable

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Duplicated study or data

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Pedersen, E & Persson Waye, K 2003, 'Wind turbine noise; dose-response relationship', In: de Jong, RG, Houtgast, T, Franssen, EAM, Hofman, WF (eds), Proceedings of the 8th International Congress on Noise as a Public Health Problem, Rotterdam, 29 June – 3 July 2003, pp. 278–279.

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Ramakrishnan, R 2009, 'Wind farms and noise', Proceedings of Inter-Noise 2009, August 2009, Ottawa, Ontario.

Salt, A & Kaltenbach, J 2011, 'Infrasound from wind turbines could affect humans', *Bulletin of Science, Technology & Society*, vol. 31, no. 4, pp. 296–302.

Thorne, R 2009, 'Assessing intrusive noise and low amplitude sound', PhD thesis, Institute of Food, Nutrition and Human Health, Massey University, New Zealand.

Van den Berg, GP 2005, 'The beat is getting stronger: the effect of atmospheric stability on low-frequency modulated sound of wind turbines', *Journal of Low Frequency Noise Vibration and Active Control*, vol. 24, no. 1, pp. 1–23.

Warren, C, Niezrecki, C & Avitabile, P 2011, 'Determination of wind turbine operating deflection shapes using full-field 3D point-tracking', Proceedings of the 29th International Modal Analysis Conference, Jacksonville, Florida.

APPENDIX D – SUMMARY OF LITERATURE PROVIDED BY THE NHMRC

Table 40 lists all articles supplied for this review by the NHMRC in categories of ‘existing literature’ and ‘submitted literature’. Literature in the ‘submitted literature’ category comprised all material that was provided to the NHMRC for consideration in the review during the public call for literature conducted in September 2012. Literature in the ‘existing literature’ category comprised material from NHMRC files on wind farms and human health, and material that had been previously submitted to the NHMRC by stakeholders.

The table identifies each document and the action taken (include or exclude) in regard to that document. Each document was retrieved and assessed by the researchers for eligibility of inclusion in the systematic reviews’ evidence-base. Documents that were included have been identified; and where a document has been excluded, the primary reason behind that action is indicated.

Table 40 Summary of literature received from the NHMRC

Author	Year	Title	Article type/source	Action
Existing literature				
BelAcoustic Consulting	2004	<i>Low-frequency noise and infrasound from wind turbine generators: a literature review</i>	Report	Narrative review, background information on turbines, no health outcomes; exclude
Board on Environmental Studies and Toxicology	2007	<i>Environmental Impacts of wind-energy projects</i>	Book	Background information on wind farms, human health outcomes not considered; exclude
CanWEA	2009	<i>Addressing concerns with wind turbines and human health</i>	Position statement	Opinion piece with list of references; exclude
Chatham-Kent Health Unit	Public 2008	<i>The health impact of wind turbines: a review of the current white, grey and published literature</i>	Report	Narrative review; exclude
Chief Medical Officer of Health (Canada)	2010	<i>The potential health impact of wind turbines</i>	Report	Narrative review; exclude
Colby WD, Dobie R, Leventhall G, Lipscomb DM, McCunney RJ, Seilo MT, Sondergaard B	2009	<i>Wind turbine sound and health effects: an expert panel review</i>	Report	Narrative review conducted by expert panel, no new/additional data presented; exclude
Fiumicelli D	2011	<i>Wind farm noise-dose response</i>	Report	Background information on wind turbine noise impacts and dose effects; exclude
Jakobsen J	2005	<i>Infrasound emission from wind turbines</i>	Report	Background information on wind turbine infrasound measurement; exclude
Knopper LD, Ollson CA	2011	<i>Health effects and wind turbines: a review of the literature</i>	Report	Systematic search of peer-reviewed literature using key words in the Web of Knowledge, key word search using Google for popular literature, narrative review of findings, no new data reported; exclude
Leventhall G	2004	<i>Low-frequency noise and annoyance</i> < http://www.noiseandhealth.org/text.asp?2004/6/23/59/31663 >	Report	Background information on wind turbine noise measurement; exclude
Massachusetts Dept of Public Health and Dept of	2012	<i>Wind turbine health impact study: report of independent expert panel</i>	Report	Background information on wind turbine features, narrative review of health impact

Environmental Protection				literature, no new data reported; exclude	
Minnesota Dept of Health, Environmental Health Division	2009	<i>Public health impacts of wind turbines</i>	Report	Background information of wind turbine features, narrative review of health impact literature, no new data reported; exclude	
Ohio Department of Health	2008	<i>Literature search on the potential health impacts associated with wind-to-energy turbine operations</i>	Report	Narrative review; exclude	
Pedersen E, Halmstad H	2003	<i>Noise annoyance from wind turbines: a review</i>	Report	Narrative review; exclude	
Roberts M, Roberts J (exponent)	2009	<i>Evaluation of the scientific literature on the health effects associated with wind turbines and low-frequency sound</i>	Report	Narrative review; exclude	
Bolin K, Bluhm G, Eriksson G, Nilsson M	2011	Infrasound and low-frequency noise from wind turbines: exposure and health effects	Journal— <i>Environmental Research Letters</i>	Narrative review; exclude	
Cappuccio FP, Cooper D, D'Elia L, Strazzullo P, Miller M	2011	Sleep duration predicts cardiovascular outcomes: a systematic review and meta-analysis of prospective studies	Journal— <i>European Heart Journal</i>	Study—population unsuitable (cardiovascular disease); exclude	
Chen HA, Narins P	2012	Wind turbines and ghost stories: the effects of infrasound on the human auditory system	Journal— <i>Acoustical Society of America</i>	Background information on wind turbine infrasound; exclude	
Hanning C, Evans A	2012	Wind turbine noise	Journal— <i>British Medical Journal</i>	Opinion paper; exclude	
Harding G, Harding P, Wilkins A	2008	Wind turbines, flicker and photosensitive epilepsy: characterising the flashing that may precipitate seizures and optimising guidelines to prevent them	Journal— <i>Epilepsia</i>	Background information on shadow flicker as possible cause of epilepsy; exclude	
Jakobsen J	2005	Infrasound emission from wind turbines	Journal— <i>Low Frequency Noise, Vibration and Active Control</i>	Background information on wind turbine infrasound; exclude	
Janssen SA, Voss H, Eisses E, Pedersen E	2011	A comparison between exposure–response relationships for wind turbine annoyance and annoyance due to other noise sources	Journal— <i>Acoustical Society of America</i>	Background information and modelling based on 3 previous studies, no new empirical data; exclude	
Kamperman GW, James RR	2009	Guidelines for selecting wind turbines sites	Journal— <i>Sound and Vibration</i>	Guidelines for turbine site selection; exclude	
McMurty R	2011	Toward a case definition of adverse health effects in the environs of industrial wind turbines: facilitating a clinical diagnosis	Journal— <i>Bulletin of Science, Technology & Society</i>	Background information on wind turbines health effects measurements; exclude	
Moller H, Pedersen CS	2011	Low-frequency noise from large wind turbines	Journal— <i>Acoustical Society of America</i>	Background information on wind turbines; exclude	

Nishimura K	1988	The effects of infrasound on pituitary adreno-cortical response and gastric microcirculation in rats	Journal— <i>Low Frequency Noise and Vibration</i>	Study—population unsuitable (non-human); exclude
Pedersen E, Persson Waye K	2008	Wind turbines: low level noise sources interfering with restoration?	Journal— <i>Environmental Research Letters</i>	Duplicate study/data—duplication of included data (Pedersen and Larsman 2008); exclude
Pedersen E, van den Berg F, Bakker R, Bouma J	2009	Response to noise from modern wind farms in The Netherlands	Journal— <i>Acoustical Society of America</i>	Study— include (also identified in the black literature search)
Persson Waye K, Rylander R, Benton S, Leventhall G	1997	Effects on performance and work quality due to low-frequency ventilation noise	Journal— <i>Sound & Vibration</i>	Background information on low-frequency noise; exclude
Phillips CV	2011	Properly interpreting the epidemiologic evidence about the health effects of industrial wind turbines nearby residents	Journal— <i>Bulletin of Science, Technology & Society</i>	Background information on wind turbine health effects; exclude
Qibai CYH, Shi H	2004	An investigation on the physiological and psychological effects of infrasound on persons	Journal— <i>Low Frequency Noise, Vibration and Active Control</i>	Background information on infrasound effects on humans; exclude
Salt A, Kaltenbach J	2011	Infrasound from wind turbines could affect humans	Journal— <i>Bulletin of Science, Technology & Society</i>	Background information on wind turbine infrasound effects; exclude
Shepherd D, McBride D, Welch D, Dirks K, Hill E	2011	Evaluating the impact of wind turbine noise on health-related quality of life	Journal— <i>Noise & Health</i>	Study— include (also identified in the black literature search)
Sloven P	2005	LFN and the A-weighting	Journal— <i>Low Frequency Noise, Vibration and Active Control</i>	Background information on technical aspects to sound measurements; exclude
Smedley A, Webb A, Wilkins A	2010	Potential of wind turbines to elicit seizures under various meteorological conditions	Journal— <i>Epilepsia</i>	Background information of shadow flicker and epileptic seizures; exclude
Spyrak CH, Papadopoulou-Daifoti Z, Petounis A	1978	Norepinephrine levels in rat brain after infrasound exposure	Journal— <i>Psychology and Behaviour</i>	Study—population unsuitable (non-human); exclude
Ambrose SE, Rand RW	2011	<i>The Bruce McPherson infrasound and low-frequency noise study</i>	Report	Opinion paper—sound measurements and personal experience of symptoms at an individual home near a turbine; exclude
Bakker HHC, Rapley BI	2011	Problems measuring low-frequency sound levels near wind farms	Conference paper	Narrative review on human perceptions and measurement of low-frequency sound near wind farms; exclude
Bray W, James R	2011	Dynamic measurements of wind turbine acoustic signals, employing sound-quality engineering methods considering the time- and frequency-sensitivities of human perception	Conference paper	Background information on low-frequency sound and human perception; exclude

Chapman S		2011	Wind farms and health: who is fomenting community anxieties?	Op-ed	Opinion paper; exclude
Chapman S		n.d.	Is there anything that wind turbines don't cause? Psychogenic aspects of 'wind turbine disease'	Presentation	Background information on psychogenic and attitudinal aspects to causes of health problems; exclude
Dickinson PJ		2012	A pragmatic view of wind turbine noise standard	Paper	Background information on NZ acoustic standards and characteristics of wind farm noise; exclude
E-coustic Solutions		n.d.	<i>Submission of comments related to proposed Ministry of the Environment Regulations to Implement the Green Energy and Green Economy Act, 2009</i>	Report	Background information on measurement of low-frequency and infrasound from wind farms, no health outcomes; exclude
enHealth		2004	<i>The health effects of environmental noise: other than hearing loss</i>	Report	Background on health effects of industrial noise; exclude
Environmental Tribunal	Review	2010	Erikson V, Director, Ministry of the Environment	Legal evidence	Tribunal presentations—insufficient study details; exclude
Frey BJ, Hadden, PJ		2012	<i>Wind turbines and proximity to homes: the impact of wind turbine noise on health</i>	Report	Narrative review; exclude
Frey BJ, Hadden PJ		2007	<i>Noise radiation from wind turbines installed near homes: effects on health</i>	Report	Narrative review; exclude
Hall N, Ashworth P, Shaw H (CSIRO)		2012	<i>Exploring community acceptance of rural wind farms in Australia: a snapshot</i>	Report	Narrative review of community attitudes to wind farms with case studies; exclude
Hanning C		2010	Wind turbine noise and sleep: the torment of sleep disturbance	Presentation	Background information on the effects of noise on sleep; exclude
Hanning, C		2010	<i>Wind turbine noise, sleep and health</i>	Report	Narrative review; exclude
Hanning C, Nissenbaum M		2011	Selection of outcome measures in assessing sleep disturbance from wind turbine noise	Conference paper	Background information on sleep and noise disturbance; exclude
Harrison J		2010	No rules, no caution, no accountability	Presentation	Background information on regulation and modelling of wind turbine noise; exclude
Harry A		2007	<i>Wind turbines, noise and health</i>	Report—case series	Study—case series selected with symptoms they attributed to wind turbines, no comparative analysis; exclude
Health Protection Agency		2010	<i>Health effects of exposure to ultrasound and infrasound</i>	Report	Background information on environmental noise and health; exclude

Health Protection Agency	2010	<i>Environmental noise and health in the UK</i>	Report	Background information on health and exposure to ultrasound and infrasound; exclude
Horner B	2012	NHMRC audit comments	Email communication	Commentary in response to the NHMRC report <i>Wind turbines and health: a rapid review of the evidence July 2010</i> ; exclude
Hubbard HH, Shepherd KP	1990	<i>Wind turbine acoustics</i>	Report	Background information on wind turbine acoustics; exclude
Ison E	2009	<i>Rapid review of health impacts of wind energy</i>	Report	Narrative review on effects of energy production and wind farms; exclude
James R	2010	No rules, no caution, no accountability	Presentation	Background information on regulation and modelling of wind turbine noise; exclude
Krogh, C	2011	<i>Brief overview of references on noise including industrial wind turbines and adverse health effects</i>	Report	Background information on the effects of noise on humans; exclude
Krogh C, Horner B	2011	<i>A summary of new evidence: adverse health effects and industrial wind turbines</i>	Report	Opinion/discussion of evidence of health effects of wind turbines; exclude
Leventhall G	2010	Wind turbine syndrome: an appraisal	Presentation	Opinion/discussion of evidence for wind turbine syndrome; exclude
Leventhall G	2003	<i>A review of published research on low-frequency noise and its effects</i>	Report	Background information on low-frequency noise and its effects; exclude
Mills DA, Manwell JF	2012	<i>A brief review of wind power in Denmark, Germany, Sweden, Vermont and Maine: possible lessons for Massachusetts</i>	Report	Narrative review of wind power in Denmark, Sweden, Germany, Vermont and Maine; exclude
Moller H, Pedersen S, Stanstrup JK, Pedersen CS	2012	<i>Assessment of low-frequency noise from wind turbines in Maastricht</i>	Report	Background information on the measurement, impact and health effects of low-frequency noise; exclude
Moorhouse A, Hayes M, Von Hunderbein S, Piper B, Adams M	2007	<i>Research into aerodynamic modulation of wind turbine noise: final report</i>	Report	Background information on aerodynamic modulation of low-frequency wind turbine noise; exclude
National Research Council	2007	<i>Environmental impacts of wind-energy projects</i>	Book	Narrative review of assessment and measurement of the impact of wind turbines on the environment; exclude
National Toxicology Program	2001	<i>Brief review of toxicological literature</i>	Report	Background information on the impact of infrasound on the environment and

humans; exclude

Nature and Society	2011		Editorial— <i>Journal of the Nature and Society Forum</i>	Opinion/discussion papers on wind farms and ecology and controversies around wind farming; exclude
New South Wales Landscape Guardians	2012	<i>Peer-reviewed studies on health impacts of wind turbines</i>	Report	Narrative review; exclude
Nissenbaum M, Aramini J, Hanning C	2011	Adverse health effects of industrial wind turbines: a preliminary report	Conference paper	Duplicate study/data—an updated version identified and included (Nissenbaum, Aramini, Hanning 2012); exclude
Oregon Health Authority	2012	<i>Strategic health impact assessment on wind energy development in Oregon</i>	Report	Narrative review and assessment of health impact of wind energy development in Oregon; exclude
Pace Energy and Climate Centre	2011	<i>Case study: Maple Ridge and High Sheldon wind farms</i>	Report	Opinion/discussion of the impact of wind farming in New York State; exclude
Pedersen E	2007	Human response to wind turbine noise: perception, annoyance and moderating factors	Thesis	Duplicate study/data—duplication of included data (Pedersen & Persson Waye 2007); exclude
Phillips C	2010	<i>An analysis of the epidemiology and related evidence on the health effects of wind turbines on local residents</i>	Report	Opinion paper; exclude
Phipps R, Amati M, McCoard S, Fisher R	2008	Visual and noise effects reported by residents living close to Manawatu wind farms: preliminary survey results	Paper	Study—self-report survey of preliminary results with no relevant health outcomes; exclude
Pierpont N	2009	<i>Wind turbine syndrome: a report on a natural experiment</i>	Book	Background information—reporting on a collection of case reports but with no comparative analysis; exclude
Punch J, James R, Pabst D	2010	Wind turbine noise: what audiologists should know	Magazine	Narrative review; exclude
Rogers AL, Manwell JF, Wright S	2006	<i>Wind turbine acoustic noise</i>	Report	Background information on wind turbine acoustic noise; exclude
Salt A	2010	Infrasound: your ears ‘hear’ it but they don’t tell your brain	Presentation	Background information on the impact of infrasound on humans; exclude
Shepherd D	2012	Response to ‘Wind farms and health: who is fomenting community anxieties?’ – Letters	Letter to editor	Commentary/opinion, correspondence with no data; exclude

Sloth E	2010	Parameters influencing wind turbine noise	Presentation	Background information on factors affecting wind turbine noise; exclude
Sonus Pty Ltd	2010	<i>Infrasound measurements from wind farms and other sources</i>	Report	Background information on infrasound measurement; exclude
Stantec Consulting	2011	<i>Health effects and wind turbines: a review for renewable energy approval applications submitted under Ontario Regulation 359/09</i>	Report	Narrative review; exclude
Stewart J	2006.	<i>Location, location, location: an investigation into wind farms and noise by the Noise Association</i>	Report	Background information on wind turbine noise and its impact; exclude
Swinbanks M	2010	Wind Energy Resource Zone Board comments: NASA–Langley wind turbine noise research	Email communication	Commentary/opinion, correspondence with no data; exclude
The Acoustics Group Pty Ltd	2011	<i>Peer review of acoustic assessment of Flyers Creek wind farm</i>	Report	Background information on acoustic assessment of a wind farm in NSW; exclude
Thorne B	2011	<i>Wind farm noise and human perception: a review</i>	Report	Background information of wind turbine effects and single case study, not systematic; exclude
Thorne R	2012	<i>Waubra & other Victorian wind farm noise impact assessments</i>	Report	Study—survey of residents living near wind farms; some health outcomes but study not yet completed; exclude
Thorne R	2007	Assessing intrusive noise and low-amplitude sound	Thesis	Background information on noise assessment; exclude
Thorne R, Shepherd D	2011	Wind turbine noise: why accurate prediction and measurement matter	Conference paper	Background information on noise measurement from wind turbines and noise annoyance; exclude
Boorowa District Landscape Guardians	Not dated	Wind energy in the Southern Tablelands	Flyer	Commentary/opinion; exclude
Unknown	2010	<i>Overview of references: adverse health effects of industrial wind turbines</i>	Report	Narrative review; exclude
Unknown	2012	<i>Summary of peer-reviewed references</i>	Report	Abstract list: with no eligible articles not previously included
Van den Berg GP	2006	<i>The sound of high winds: the effect of atmospheric stability on wind turbine sound and microphone noise</i>	Book/Report	Background information on wind turbine noise and measurement; exclude
Van den Berg GP	2003	Wind turbines at night: acoustical practice and sound research	Conference paper	Background information on wind turbine noise at night; exclude

Von Hunerbein S, King A, Hargreaves J, Moorhouse A, Plack C	2010	<i>Perception of noise from large wind turbines</i>	Report	Background information on wind turbine noise perception and annoyance thresholds for measurement; exclude
World Health Organization	2011	<i>Burden of disease from environmental noise: quantification of healthy life years lost in Europe</i>	Report	Background information on environmental noise; exclude
Submitted Literature				
Acoustic Ecology Institute	2009	<i>Wind turbine noise impacts</i>	Report	Background information on wind energy noise impact; exclude
Acoustic Ecology Institute (compiled by Jim Cummings)	2011	<i>Wind turbine noise: science and policy overview</i>	Report	Background information on policy for wind farming; exclude
Acoustic Group Pty Ltd, The	2012	<i>Review of Draft Wind Farm Guidelines 42.4963.R2:ZSC</i>	For Flyers Creek Wind Turbine Awareness Group Inc., 14 March 2012	Background information on wind farm guidelines; exclude
Acoustic Group Pty Ltd, The	2012	<i>Peer Review of Noise Impact Assessment, Stony Gap Wind Farm 42.4989.R1:ZSC</i>	Prepared for Regional Council of Goyder, 26 May 2012	Background information on acoustic assessment of a wind farm proposal; exclude
Adcock J, Delaire C, Griffen D	2012	A review of the Draft NSW Planning Guidelines: wind farms	<i>Acoustics Australia</i> 2012; 40:1	Guidelines/regulations for wind farms; exclude
The Acoustic Ecology Institute	2009	<i>AEI Special Report: Wind energy noise impacts</i>	Available from <www.acousticecology.org>	Background information on wind energy noise impact; exclude
The Acoustic Ecology Institute	2011	<i>Wind farm noise 2011: science and policy overview</i>	Available from <www.acousticecology.org>	Background information on policy for wind farming; exclude
Alves-Pereira M, Castelo Branco NAA	2007	Vibroacoustic disease: biological effects of infrasound and low-frequency noise explained by mechanotransduction cellular signaling	<i>Progress in Biophysics and Molecular Biology</i> 2007; 93(1–3):256–279	Background information on vibroacoustic disease; exclude
Alves-Pereira M, Castelo Branco NAA	2007	Public health and noise exposure: the importance of low-frequency noise	Proceedings of the InterNoise Conference, Istanbul, Turkey, pp. 3–20	Background information on low-frequency noise impact; exclude
Alves-Pereira M, Castelo Branco NAA	2011	Low-frequency noise and health effects, June 2011	Presented at the NHMRC forum Wind Farms and Human Health, 7 June 2011	Background information on possible health effects of low-frequency noise; exclude
Alves-Pereira M, Castelo Branco NAA	2007	In-home wind turbine noise is conducive to vibroacoustic disease	Second International Meeting on Wind Turbine Noise, Lyon, France, 20–21 September 2007	Background information on vibroacoustic disease; exclude

Ambrose R	2009		Letter to Carman Krogh Pharm	Commentary/opinion—letter; exclude
Ambrose SE, Rand RW, Krogh CME	2012	Wind turbine acoustic investigation: infrasound and low-frequency noise: a case study	<i>Bulletin of Science, Technology & Society</i> , doi: 10.1177/0270467612455734	Study—does not include exposed population and health outcomes; exclude
Ambrose SE, Rand RW, Krogh CME	2012	Falmouth, Massachusetts wind turbine infrasound and low-frequency noise measurements	Presented at InterNoise 2012 19–22 August 2012, New York City	Background information on wind turbine noise measurement, no health outcomes; exclude
Ambrose SE, Rand RW, Krogh CME	2012	Industrial wind turbines and health: wind turbines can harm humans if too close to residents. A summary of some peer-reviewed and conference articles, their abstracts and citations, regarding adverse health effects and wind turbines	<i>Bulletin of Science Technology & Society</i> , published online 17 August 2012	List of abstracts with no additional articles meeting inclusion criteria; exclude
Appelqvist P, Almgren M	2011	Wind turbine noise in sheltered dwelling areas	Fourth International Meeting on Wind Turbine Noise, Rome, Italy, 12–14 April 2011	Not found by cut-off date; exclude
Australian Academy of Technological Sciences and Engineering (ATSE)	2009	The hidden costs of electricity: externalities of power generation in Australia		Background information on cost of power generation; exclude
Babish W	2011	Cardiovascular effects of noise	Editorial commentary, <i>Noise Health</i> 2011; 13:201–204	Background information on effects of noise on health; exclude
Baerwald EF, D'Amours GH, Klug BJ, Barclay RMR	2008	Barotrauma is a significant cause of bat fatalities at wind turbines	Department of Biological Sciences, University of Calgary, Calgary, in: <i>Current Biology</i> 2008; 18:16	Study—unsuitable population; exclude
Bakker H, Bennett D, Rapley B, Thorne R	2009	Seismic effect in residents from 3 MW wind turbines	Presented at the Third International Meeting on Wind Turbine Noise, Aalborg, Denmark, 17–19 June 2009	Background information on seismic effects of wind turbines in NZ, no health outcomes; exclude
Bakker H, Rapley B	2010	Sound characteristics of multiple wind turbines	<i>Sound, Noise, Flicker and the Human Perception of Wind Farm Activity</i> , pp. 233–258	Background information on wind turbine sound; exclude
Bakker H, Bennett D, Rapley B, Thorne R	2010	Seismic effects on residents from wind turbines	Rapley and Bakker (eds) 2010, pp. 225–231	Background information on seismic effects of wind turbines; exclude
Barrett N	2012	Getting the wind up: exploring the concern about		Narrative review; exclude

		adverse health effects of wind power in Australia and Europe		
Bartholomew R, Wessely S	2002	Protean nature of mass sociogenic illness: from possessed nuns to chemical and biological terrorism fears	<i>British Journal of Psychiatry</i> 2002; 180:300–306	Background information only; exclude
Bartlett DJ, Marshall NS, Williams A, Grunstein RR	2008	Predictors of primary medical care consultation for sleep disorders	<i>Sleep Medicine</i> 2008; 9:857–864	Background information only; exclude
Bengtsson J, Persson Waye K, Kjellberg A	2004	Sound characteristics in low-frequency noise and their relevance for the perception of pleasantness	<i>Acta Acoustica</i> 2004; 90:171–180	Background information on low-frequency noise; exclude
Bengtsson J, Persson Waye K, Kjellberg A	2004	Evaluations of effects due to low-frequency noise in a low demanding work situation	<i>Journal of Sound and Vibration</i> 2004; 278:83–99	Background information on low-frequency noise; exclude
Berglund B, Hassmen P, Job SR F	1996	Sources and effects of low-frequency noise	<i>Journal of the Acoustical Society of America</i> 1996; 99:2985–3002	Background information on low-frequency noise; exclude
Bin YS, Marshall NS, Glozier N	2012	The burden of insomnia on individual function and healthcare consumption in Australia	<i>Australian and New Zealand Journal of Public Health</i> 2012; online doi: 10.1111/j.1753-6405.2012.00845.x	Background information only; exclude
Boss LP	1997	Epidemic hysteria: a review of published literature	<i>Epidemiological Review</i> 1997; 19(2)	Background information only; exclude
Bowdler D	2008	Amplitude modulation of wind turbine noise: a review of the evidence	<i>Acoustics Bulletin</i> 2008; 33(4)	Background information on technicalities of wind turbine noise; exclude
Bowdler D	2012	Wind turbine syndrome: an alternative view	<i>Acoustics Australia</i> 2012; 40(1)	Commentary/opinion paper; exclude
Bradley JS	1994	Annoyance caused by constant-amplitude and amplitude-modulated sound containing rumble	<i>Noise Control Engineering Journal</i> 1994; 42:203–208	Background information on annoyance of noise; exclude
Bronzaft AL	2011	The noise from wind turbines: potential adverse impacts on children's well-being	<i>Bulletin of Science Technology & Society</i> 2011; 31:291	Background information on wind turbine noise effects on children; exclude
Brooks D		Peer-reviewed studies of wind turbine health impacts		List of references, no additional articles for inclusion; exclude
Brooks D	2012	<i>NSW Planning Guidelines: wind farms: a resource for the community, applicants and consent authorities</i> (draft)	Submission to the NSW Department of Planning & Infrastructure By Parkesbourne/Mummel Landscape Guardians Inc.	Guidelines/regulations on wind farm planning; exclude

Brown County Board of Health	2012	Brown County Board of Health resolution requesting emergency state aid for families suffering around industrial wind turbines		Commentary/opinion; exclude
Bruni O, Novelli L, Ferri R	2011	<i>Sleep disturbance and wind turbine noise</i>	Sapienza University, Rome, Italy and Institute for Research on Mental Retardation and Brain Aging, Troina, Italy	Background information on noise effects on children; exclude
Canadian Wind Energy Association	2011	Canadian Wind Energy Association responds to October 14 2011 statement by Wind Concerns Ontario		Commentary/opinion, links to related wind farm documents; revealed no new references; exclude
Capuccio FP, Cooper D, D'Elia L, Strazzullo P, Miller MA	2011	Sleep duration predicts cardiovascular outcomes: a systemic review and meta-analysis of prospective studies	<i>European Heart Journal</i> 2011; 32(12):1484–1492; Epub 7 Feb 2011	Background information only; exclude
Castelo Branco NAA, Alves-Pereira M	2004	Vibroacoustic disease	<i>Noise & Health</i> 6 (23), 320	Background information only; exclude
Le Groupe de Travail		Le retentissement du fonctionnement des éoliennes sur la sante de l'homme	Academie Nationale de Medecine	Language not English; exclude
Ceranna L, Hartmann G, Henger M	2005	The inaudible noise of wind turbines	Conference paper, Infrasound Workshop Nov 28 – Dec 02 2005, Tahiti (Federal Institute for Geosciences and Natural Resources)	Background information on wind turbine noise; exclude
Chao P, Yeh C, Juang Y, Hu C, Chen C	2012	Effect of low-frequency noise on the echocardiographic parameter E/A ratio	<i>Noise Health</i> 2012; 14:155–158	Background information on the effects of low-frequency noise; exclude
Chapman S	2011	Wind farms and health: who is fomenting community anxieties?	<i>Medical Journal of Australia</i> 2011; 195(9)	Commentary/opinion; exclude
Chapman S	2012	Submission to NSW Wind Farm Guidelines	School of Public Health, University of Sydney	Narrative review; exclude
Chapman S, George A	2006	A disease in search of a cause: a study of self-citation and press release pronouncement in the factoid of wind farms causing 'vibroacoustic disease'	School of Public Health, University of Sydney	Background information on vibroacoustic disease; exclude
Chen HA, Narins P		Wind turbines and ghost stories: the effects of infrasound on the human auditory system		Background information on technical aspects of infra sound from wind turbines; exclude

Chouard C-H		Impacts of wind turbine operation on humans	National Academy of Medicine	Background information only; exclude
Comite senatorial permanent de l'energie, de l'environnement et des ressources naturelles	2011	Les eoliennes industrielles et la sante. Les eoliennes peuvent causer du tort aux humains	Le 18 octobre 2011	Language not English; exclude
Cooper D	2012	Peer review of noise impact assessment, Stony Gap Wind Farm 42.4989.R1:ZSC	Prepared for Regional Council of Goyder, 26 May 2012 (The Acoustic Group Pty Ltd)	Background information on wind turbine noise assessment; exclude
da Fonseca J, dos Santos JM, Branco NC, Alves-Pereira M, Grande N, Oliveira P, Martins AP	2006	Noise-induced gastric lesions: a light and scanning electron microscopy study of the alterations of the rat gastric mucosa induced by low-frequency noise	<i>Central European Journal of Public Health</i> 2006; 14(1):35–38	Study—unsuitable population; exclude
Davis J	2007	Noise pollution from wind turbines	Presented at the Second International Meeting on Wind Turbine Noise, Lyon, France	Commentary/opinion; exclude
Dean D	2007	Wind turbine mechanical vibrations: potential environmental threat		Commentary/opinion—letter; exclude
Dean R		Infrasound modulation of 1000 Hz one-third octave		Background information only; exclude
DeGagne DC, Lapka SD	2008	Incorporating low-frequency noise legislation for the energy industry in Alberta, Canada	<i>Journal of Low Frequency Noise, Vibration and Active Control</i> 2008; 27(2):105–120	Background information on measurement and legislation of low-frequency noise for the Canadian energy industry; exclude
Department of Planning and Community Development (Victoria)	2011	Policy and planning guidelines for development of wind energy facilities in Victoria, August 2011		Guidelines/regulations on policy and planning; exclude
Deutscher Akkreditierungs Rat	2004	Measurement of the acoustic noise emission of the IT 77/1500 CIII H80 wind turbine; Report no. DEWIS AM 138/04, 2004-07-23		Background information on noise measurement; exclude
Devine-Wright P	2011	Public engagement with large-scale renewable energy technologies: breaking the cycle of NIMBYism	WIREs Climate Change 2011; 2(1):19–26	Background information on the public and renewable energy; exclude
Dickinson PJ	2009	Submission to Standards NZ 6808:2009 Acoustics – wind farm noise		Discussion on NZ acoustic standards and characteristics wind farm noise; exclude
Dickinson PJ	2009	Nonsense on stilts	Proceedings of Acoustics 2009, 23–25 November 2009, Adelaide,	Testimonial submission to Standards NZ; exclude

Australia

Dickinson PJ	2010	Sounds from wind turbines: theory, practice, assumptions and reality	In: Rapley and Bakker (eds) 2010), pp. 181–205	Discussion only; exclude
Doolan CJ, Moreau DJ, Brooks LA	2012	Wind turbine noise mechanisms and some concepts for its control	<i>Acoustics Australia</i> 2012; 40(1)	Background information on turbine noise mechanism; exclude
Ecker LS, Ullrich KH, Seifert CM, Schwarz N, Cook J	2012	Misinformation and its correction: continued influence and successful debiasing	<i>Psychological Science in the Public Interest</i> 2012; 13:3106–3131	Background information only; exclude
Elliott SJ	2005	Feedback control of engineering structures and in the inner ear	Forum Acusticum 2005, Budapest	Background information only; exclude
Environment Protection Authority (NSW)	2000	<i>NSW Industrial Noise Policy, January 2000</i>	Retrieved from < www.environment.nsw.gov.au/noise/industrial.htm >	Background information on industrial noise policy; exclude
Environment Protection Authority (South Australia)	2009	<i>Wind farms environmental noise guidelines</i> , July 2009		Background information on guidelines for wind farms; exclude
Environmental review tribunal	2011	Erickson Vv, Director, Ministry of the Environment		Court proceedings; exclude
Etherington J	2009	<i>The wind farm scam: an ecologist's evaluation</i>	Stacey International, 2009	Commentary/opinion; exclude
Falmouth Board of Health	2012	Health effects of wind turbines		Summary of testimonial submissions; exclude
Falmouth Health Department	2012	Request that Mass DPH immediately initiate a health assessment of the impacts of the operation of wind turbines in Falmouth	Letter to Ms Condon	Commentary/opinion paper; exclude
Feldmann J, Pitten FA	2004	Effects of low-frequency noise on man: a case study	<i>Noise Health</i> 2004;7:23–28	Background information on infrasound; exclude
Findeis H, Peters E	2004	Disturbing effects of low-frequency sound immissions and vibrations in residential buildings	<i>Noise Health</i> 2004;6:29–35	Background information on low-frequency sound; exclude
French Academy of Medicine	2006	Repercussions of wind turbine operations on human health	< http://ventdubocage.net/documentsoriginaux/sante/eoliennes.pdf >	Language not English; exclude
Frey BJ, Hadden PJ	2007	Noise radiation from wind turbines installed near homes		Narrative review on wind turbine noise and health; exclude
Friends of Collector Inc.	2012	Submission to the New South Wales Department of Planning and Infrastructure 'NSW Planning	Mr Tony Hodgson, Inaugural President, Friends of Collector	Salt, McMurty and Cooper papers—background information only; Wang study—

		Guidelines -Windfarms'	Inc.	see Wang V entry; exclude all
Friends of Collector Inc.	2011	Submission to the Senate Community Affairs Committee Inquiry into the Social and Economic Impacts of Rural Wind Farms	Mr Tony Hodgson, Inaugural President, Friends of Collector Inc.	Background information on wind farm impacts on health; exclude
Geen RG, McCown EJ	1984	Effects of noise and attack on aggression and physiological arousal	<i>Motivation and Emotion</i> 1984; 8:231–241	Background information only; exclude
Genuit K	2007	Tiefe Frequenzen sind nicht gleich tiefe Frequenzen – Tieffrequente Geräuschanteile und deren (Lärm-)Wirkungen. (LFN does not equal LFN – LF components of sound and their effects (on man))	HEAD acoustics GmbH; conference paper – DAGA 2007	Language not English; exclude
Gillespie EK	2011	WPD (White Pines Project), Prince Edward County, Ontario (the 'Project')	Letter to Mr K Surette, WPD, Canada, 8 November 2011	Commentary/opinion—letter; exclude
Gillespie EK	2011	Ministry of the Environment webpage: 'The sound of science'	Letter to various recipients, 23 November 2011	Commentary/opinion—letter; exclude
Gillespie EK	2012	Ministry of the Environment Media Release 'Expert report Confirms no direct health effects from wind turbines'	Letter to various recipients, 3 January 2012	Commentary/opinion—letter; exclude
Grewal T, James C, Macefield VG	2011	Frequency-dependent modulation of muscle sympathetic nerve activity by sinusoidal galvanic vestibular stimulation in human subjects	<i>Journal of Occupational and Environmental Medicine</i> 2011; 53(2):146–152	Background information only; exclude
Griefahn B, Basner M	2011	Disturbances of sleep by noise	Paper no. 107, Proceedings of Acoustics 2011, 2–4 November 2011, Gold Coast, Australia	Background information on sleep disturbance; exclude
Gueniot C.	2006	Le retentissement du fonctionnement des éoliennes sur la santé de l'homme ('Repercussions of wind turbine operations on human health')	Wind turbines: The Academy cautious, Panorama du médecin, 20 March 2006, reporting on National Academy of Medicine in France	Language not English; exclude
Guest M, Boggess M, D'Este C, Attia J, Brown A	2011	An observed relationship between vestibular function and auditory thresholds in aircraft-maintenance workers	School of Health Sciences, University of Newcastle, Australia, <i>Journal of Occupational and Environmental Medicine</i> 2011; 53(2):146–152	Background information only; exclude

Hansen C	2010	Assessment of noise from the proposed wind farm development around Mt Bryan, near the township of Hallett	Prepared for Environment, Resources and Development Court, SA, by School of Mechanical Engineering, University of Adelaide, South Australia	Not found by cut-off date; exclude
Hanning C	2010	Sleep disturbance and wind turbine noise	On behalf of the Northumberland & Newcastle Society	Narrative review; exclude
Hanning C	2012	Wind turbine noise, sleep and health	Response to: The Northumberland County Council Core Issues and Options Report Consultations	Narrative review; exclude
Hanning CD, Evans A	2012	Wind turbine noise (editorial)	<i>British Medical Journal</i> 2012; 344:e1527 doi: 10.1136/bmj.e1527 (published 8 March 2012)	Commentary/opinion—editorial; exclude
Harding G, Harding P, Wilkins A	2008	Wind turbines, flicker and photosensitive epilepsy: characterizing the flashing that may precipitate seizures and optimizing guidelines to prevent them	<i>Epilepsia</i> 2008; 49(6):1095–1098	Background information on wind turbine flicker; exclude
Harrison J P	2011	Wind turbine noise	<i>Bulletin of Science, Technology & Society</i> 2011; 31:256–261	Background information on wind turbine noise; exclude
Hatfield J, Job RF, Hede AJ, Carter NL, Peploe P, Taylor R et al.	2002	Human response to environmental noise: the role of perceived control	<i>Journal of Behavioural Medicine</i> 2002;9:341–359	Background information on environmental noise; exclude
Hauser W, Hansen E, Enck P	2012	Nocebo phenomena in medicine	<i>Deutsches Arzblatt International</i> 2012; 109(26):459–465	Background information only; exclude
Havas M, Colling D	2011	Wind turbines make waves: why some residents near wind turbines become ill	Published online before print 30 September 2011, doi: 10.1177/0270467611417852; <i>Bulletin of Science, Technology & Society</i> 2011; 31:414–426	Background information on possible health associations with wind turbines; exclude
Health Canada	2009	Health Canada's response to the Digby Wind Power Project Addendum, Digby, Nova Scotia	Email correspondence to Mr Sanford, 6 August 2009	Commentary/opinion—letter; exclude
Health Canada	2010	Useful information for environmental		Background information only; exclude

		assessments		
Health Canada	1986	<i>Achieving health for all: a Framework for health promotion</i>	Webpage	Background information only; exclude
Health Canada	2012	<i>Community noise annoyance</i>	Copy of webpage	Background information only; exclude
Health Canada	2009	<i>Mental health: anxiety disorders</i>	Fact sheet	Background information only; exclude
Health Canada	2012	<i>Mental health</i>	Copy of webpage	Background information only; exclude
Health Canada	2008	<i>Mental health: coping with stress</i>	Fact sheet	Background information only; exclude
Hegarty & Elmgree Lawyers	2012	Wind farms and human health	Letter to Profs Anderson and McCallum acting on behalf of Friends of Collector Inc.	Commentary/opinion—letter; exclude
Horner B	2012	Open letter audit: National Health and Medical Research Council updated literature review and NHMRC updated public statement	Letter to Profs Anderson and McCallum at the NHMRC, and Dr Bruce Armstrong, University of Sydney	Commentary/opinion—letter; exclude
Horner B	2012	Comment on the ‘Wind Turbine Impact Study: Report of independent expert panel, January 2012, prepared for Massachusetts Department of Environment Protection, Massachusetts Department of Public Health’		Commentary/opinion—letter; exclude
Horner B, Jeffery RD, Krogh CME	2011	Literature reviews on wind turbines and health: are they enough?	<i>Bulletin of Science Technology & Society</i> 2011; 31:399	Background information on effectiveness of literature reviews of the health effects of wind turbines; exclude
Howe Gastmeier Chapnik Limited	2010	Low-frequency noise and infrasound associated with wind turbine generator systems: a literature review.	Ontario Ministry of the Environment RFP no. OSS-078696	Background information on wind turbine noise; exclude
Hubbard HH, Shepherd KP	1990	<i>Wind turbine acoustic</i>	NASA Technical Paper 3057 DOE/NASA/20320-77	Background information on wind turbine acoustics; exclude
Hygge S	2011	Noise and cognition in children	University of Gävle, Gävle, Sweden, Elsevier BV	Background information only; exclude
IBM Consulting Services	2002	Traffic noise outside the home POR-02-65-S	HealthInsider 2002	Background information only; exclude
Independent Australia	2012	Study shows why misinformation works	< http://www.independentaustalia.net/2012/environment/why-misinformation-works/ >	Background information only; exclude
Institute for Clinical Evaluative Sciences, Public	2012	<i>Seven more years: the impact of smoking, alcohol, diet, physical activity and stress on</i>	Report	Background information only; exclude

Intergovernmental Panel on Climate Change	2012	Renewable energy sources and climate change mitigation		Background information only; exclude
Inukai Y, Taya H, Yamada S	2005	Thresholds and acceptability of low-frequency pure tones by sufferers	<i>Journal of Low Frequency Noise, Vibration and Active Control</i> 2005; 24(3):163–169, doi:10.1260/026309205775374433	Background information on low-frequency sound; exclude
Iser D	2004	Local wind farm survey	Dr David Iser's findings at Toora, Victoria, 2004	Study—case series, no comparative analysis; exclude
Ising H, Lange-Asschenfeldt H, Moriske H, Born J, Eilts M	2004	Low-frequency noise and stress: bronchitis and cortisol in children exposed chronically to traffic noise and exhaust fumes	<i>Noise Health</i> 2004; 6:21–28	Background information on low-frequency noise and health effects; exclude
James RR	2012	Wind turbine infra- and low-frequency sound: warning signs that were not heard	<i>Bulletin of Science, Technology & Society</i> 2012; 32(2):108–127	Background information on wind turbine low-frequency and infrasound; exclude
Johansson M	2012	Speech at the General Meeting of Vestas	Thursday 29 March 2012, Aarhus Concert Hall	Commentary/opinion; exclude
Jones, GP, Lukashkina, VA, Russell, IJ, Lukashkin, AN	2010	The vestibular system mediates sensation of low-frequency sounds in mice	<i>Journal of the Association for Research in Otolaryngology</i> , 2010; 11(4):725–732	Study—unsuitable population; exclude
Jung SS, Cheung W	2008	Experimental identification of acoustic emission characteristics of large wind turbines with emphasis on infrasound and low-frequency noise	<i>Journal of Korean Physical Society</i> ; 53:1897–1905	Background information on wind turbine low-frequency noise and infrasound; exclude
Kaiser-Wilhelm-Koog GmbH	2006	WINDTEST	Report of acoustical emissions of a wind turbine generator system type Acciona AW 82/1500 IEC IIIb T80A LM40.3P in the Moncayuelo wind farm in Spain	Background information only; exclude
Kamp F, Sottek R, Fiebig A	2012	Lautheitswahrnehmung von tieffrequenten Schallen (Perception of loudness of low-frequency sounds)	HEAD acoustics GmbH; Conference paper, DAGA 2012	Language not English; exclude
Kasprzak C		The influence of infrasounds on the electrocardiograph patterns in humans	<i>Acoustic and Biomedical Engineering</i> 2010; 118(1)	Background information on effects of infrasound; exclude
Keith SE, Michaud DS, Bly SHP	2008	A proposal for evaluating the potential health of wind turbine noise for projects under the	<i>Journal of Low Frequency Noise, Vibration and Active Control</i>	Background information on wind turbine noise evaluation; exclude

		Canadian Environmental Assessment Act	2008; 27(4):253–265	
Kemp AJ	2010	Written correspondence with medical opinion	Medical information evidence of non-compliance	Commentary/opinion—letter; exclude
Knopper LD, Ollson C	2011	Health effects and wind turbines: a review of the literature	<i>Environmental Health</i> 2011; 10:78 < http://www.ehjournal.net/content/10/1/78 >	Narrative review; exclude
Krahé D.	2008	Why is sharp-limited low-frequency noise extremely annoying?	Conference paper, Acoustics08, Paris, June 29 – July 4 2008	Background information only; exclude
Krogh CME	2010	A gross Injustice	Paper presented to the First International Symposium on Adverse Health Effects from Wind Turbines, Picton, Ontario, 29–31 October 2010	Commentary/opinion; exclude
Krogh CME	2012	Adverse health effects and industrial wind turbines	Letter to Profs Anderson and McCallum at the NHMRC	Commentary/opinion—letter; exclude
Krogh CME	2011	Industrial wind turbine development and loss of social justice?	<i>Bulletin of Science Technology & Society</i> 2011; 31:321	Background information on social justice and wind energy; exclude
Krogh CME	2012	Notice to stakeholders: Health Canada Wind Turbine Noise and Health Study	Letter to Prime Minister Stephen Harper, Office of the Prime Minister, Ottawa	Commentary/opinion—letter; exclude
Krogh CME, Gillis L, Kouwen N	2011	A self-reporting survey of adverse health effects associated with industrial wind turbines: the need for vigilance	WindVOICE - Wind Vigilance for Ontario Communities	Study; include
Krogh CME, Horner B	2012	Open letter; peer review; Health Canada Wind Turbine Noise and Health Study		Narrative review; exclude
Krogh CME, Jeffery RD, Aramini J, Horner B	2012a	Wind turbine noise perception, pathways and effects: a case study	Inter-Noise Congress, 19–22 August 2012, New York City	Background information on wind turbine noise perception; exclude
Krogh CME, Jeffery RD, Aramini J, Horner B	2012b	Annoyance can represent a serious degradation of health—wind turbine noise: a case study	Inter-Noise Congress, 19–22 August 2012, New York City	Background information on wind turbine noise and annoyance; exclude
Krogh CME, Jeffery RD, Aramini J, Horner B	2012c	Wind turbines can harm humans: a case study	Inter-Noise, 19–22 August 2012, New York City	Background information only; exclude
Laurie S	2010	Blood pressures elevating dangerously after night-time wind turbine exposure (Australia)	< www.windturbinesyndrome.com/news/ >	Background information on wind turbine syndrome; exclude
Leake J, Byford H	2009	Officials cover up wind farm noise report	<i>The Sunday Times</i> , 13 December	Commentary/opinion; exclude

2009

Legislative Assembly of Ontario	2009	Official Report of Debates (Hansard), Standing Committee on General Government; Green Energy and Green Economy Act 2009		Background information only; exclude
Leventhall G	2006	Infrasound from wind turbines: fact, fiction or deception	<i>Canadian Acoustics</i> 2006; 34(2): 29	Background information on wind turbine infrasound; exclude
Leventhall G	2005	How the 'mythology' of infrasound and low-frequency noise related to wind turbines might have developed	First International Meeting on Wind Turbine Noise: Perspectives for Control, Berlin 17–18 October 2005	Commentary/opinion; exclude
Leventhall G	2009	Wind turbines: large, small and unusual	Presentation	Background information only; exclude
Leventhall G	2009	Wind turbine syndrome: an appraisal		Commentary/opinion; exclude
Leventhall G	2011	Wind farms and human health	Presentation	Background information only; exclude
Leventhall G, Pelmeier P, Benton S	2003	A review of published research on low-frequency noise and its effects	Department of the Environment, Food and Rural Affairs, Defra Publications, London, England	Background information on low-frequency noise; exclude
Maruyama Y		Noise issue report		Language not English; exclude
Maruyama Y		Capacity x distance		Language not English; exclude
Maschke C, Niemann H	2007	Health effects of annoyance induced by neighbour noise	<i>Noise Control Engineering Journal</i> 2001; 55(3):348–356(9)	Background information on annoyance caused by noise; exclude
McBride D, Rapley B	2010	Blade flicker, shadow flicker, glint: potential hazards of wind turbines	Rapley and Bakker (eds) 2010, pp. 79–92	Background information on potential impacts of wind turbines; exclude
McMurtry R	2011	Appendix C: Evidence of known adverse health effects to industrial wind turbines	Submitted to the Appeal for Renewable Energy Approval issued to Kent Breeze Corp. and MacLeod Windmill Project Inc. (Kent Breeze Wind Farms) c/o Suncor Energy Services Inc., EBR Registry Number 011-1039 Chatham-Kent, 16 January 2011	Narrative review; exclude
McMurtry R, Nissenbaum MA, Hanning C, Jeffery RD, Harrison J, James R, White DL, Horner B, Harrington B, Krogh CME	2010	A primer on adverse health effects and industrial wind turbines, March 2010	Prepared by the Society for Wind Vigilance < www.windvigilance.com/primer_ahe.aspx >	Commentary/opinion; exclude

McMurtry R, Nissenbaum MA, Hanning C, Jeffery RD, Harrison J, James R, White DL, Horner B, Harrington B, Krogh CME	2010	Haste makes waste: an analysis of the National Health and Medical Research Council's <i>Wind turbines and health, a Rapid review of the evidence</i> , July 2010'	Prepared for the Society for Wind Vigilance	Background information—discussion and analysis of the NHMRC 2010 rapid review; exclude
McMurtry RY	2011	Toward a case definition of adverse health effects in the environs of industrial wind turbines: facilitating a clinical diagnosis	<i>Bulletin of Science Technology and Society</i> 2011; 31:316	Background information on how to define health effects of wind turbines; exclude
Mechanical Engineering Testing & Consulting	2010	Assessment of noise from the proposed wind farm development around Mt Bryan, near the township of Hallett	Prepared for Environment, Resources and Development Court, SA, by School of Mechanical Engineering, University of Adelaide, South Australia	Background information on wind farm noise assessment; exclude
Michaud DS, Bly SHP, Keith SE	2008	Using a change in percentage highly annoyed with noise as a potential health effect measure for projects under the Canadian Environmental Assessment Act	<i>Canadian Acoustics</i> 2008; 36(2):13–28	Background information on noise annoyance as a health effect; exclude
Michaud DS, Keith SE, McMurchy D	2005	Noise annoyance in Canada	<i>Noise & Health</i> 2005; 7(27):39–47	Background information on noise annoyance as a health effect; exclude
Michaud DS, Keith SE, McMurchy D	2007	A proposal for evaluating the potential health of wind turbine noise for projects under the Canadian Environmental Assessment Act	Second International Meeting on Wind Turbine Noise, Lyon, France, 20–21 September 2007	Background information on wind turbine noise evaluation; exclude
Mirowska M, Mroz E	2000	Effect of low-frequency noise at low levels on human health in light of questionnaire investigation	<i>Proceedings of Inter-Noise Congress</i> 2000; 5:2809–2812	Background information on low-frequency noise and human health; exclude
Moller H, Pedersen CS	2011	Low-frequency noise from large turbines	Section of Acoustics, Aalborg University; <i>J Acoustical Society America</i> 2011; 129:3727–3744	Background information on noise description of wind turbines ; exclude
Moller H, Pedersen CS	2004	Hearing at low and infrasonic frequencies	<i>Noise and Health</i> 2004; 6(23):37–57	Background information only; exclude
Moller H, Pedersen CS	2011	Low-frequency wind turbine noise	<i>Journal of the Acoustical Society of America</i> 2011; 129(6):3725–3743	Background information on noise description of wind turbines; exclude
Morris M	2012	Waterloo Wind Farm Survey		Links 2,3 and 4 opinion papers/letters only;

						exclude. Link 1 included for additional data to Morris 2012 Survey.
Morris M	2012	Waterloo Wind Farm Survey April 2012: Part 2—Graphs	This document is to be read in conjunction with ‘Waterloo Wind Farm Survey April 2012 – Select Committee’ by M Morris			Study; include
New South Wales Landscape Guardians Inc.	2011a	What is wrong with the current noise assessment for wind turbines in NSW? July 2011				Commentary/opinion; exclude
New South Wales Landscape Guardians Inc.	2012	Submission to Health Canada regarding Health Canada Wind Turbine Noise and Health Study, August 2012				Not found by cut-off date; exclude
New South Wales Landscape Guardians, Inc.	2011b	Grounds for an appeal against NSWLEC 59 [2007] and NSWLEC 1102 [2010], the Taralga and Gullen Range Wind Farm Cases, August 2011				Commentary/opinion; exclude
New South Wales. Parliament, Legislative Council; General Purpose Standing Committee No. 5	2009	Rural wind farms				Background information on legislation for wind farm projects; exclude
New South Wales. Parliament, Legislative Council; General Purpose Standing Committee No. 5	2009	Inquiry into rural wind farms	Media release, Wednesday 16 December 2009			Commentary/opinion; exclude
NHS Choices	2010	Wind turbine sound 'needs research'	NHS Knowledge Service 28, January 2010			Commentary/opinion; exclude
Niemann H, Bonnefoy X, Braubach M, Hecht K, Maschke C, Rodrigues C, Robbel N.	2006	Noise-induced annoyance and morbidity results from the pan-European LARES study	<i>Noise Health</i> 2006; 8:63–79			Background information on annoyance caused by noise; exclude
Niemann H, Maschke C	2004	WHO LARES: report on noise effects and morbidity				Background information on noise and morbidity; exclude
Nissenbaum MA	2010	Wind turbines, health, ridgelines and valleys				Duplicate study/data—an updated version identified and included (Nissenbaum, Aramini, Hanning 2012); exclude
Nissenbaum MA	2009	Mars Hill Wind Turbine Project health effects: preliminary findings	Presentation to Maine Medical Association, March 2009			Preliminary study data presented in PowerPoint, with no comparative analysis;

exclude

Nissenbaum MA, Aramini JJ, Hanning CD	2011	Adverse health effects of industrial wind turbines: a preliminary report	Conference paper, 10th International Congress on Noise as a Public Health Problem (ICBEN) 2011, London, UK	Duplicate study/data—an updated version identified and included (Nissenbaum, Aramini, Hanning 2012); exclude
Nissenbaum MA, Aramini JJ, Hanning CD	2012	Effects of industrial wind turbine noise on sleep and health	<i>Noise & Health</i> 2012; 14(60):237–43	Study; include
Nobbs B, Doolan CJ, Moreau DJ	2012	Characterisation of noise in homes affected by wind turbine noise	Australian Acoustical Society	Background information on characterisation of wind turbine noise; exclude
Noise Association, The (UK)	2009	Location, location, location: an investigation into wind farms and noise by the Noise Association	< http://windconcernsontario.files.wordpress.com/2009/07/ukna-windfarmreport.pdf >	Background information on wind turbine location impact; exclude
Ogido R, Costa EA, Machado Hda C	2009	Prevalence of auditory and vestibular symptoms among workers exposed to occupational noise	Departamento de Medicina Preventiva e Social, Universidade Estadual de Campinas, Campinas, SP, Brazil; <i>Revista de Saude Publica</i> 2009; 43(2):377–380	Language not English; exclude
O’Neal RD, Hellweg RD Jr, Lampeter RM	2011	Low-frequency noise and infrasound from wind turbines	<i>Noise Control Engineering</i> 2011; 59(2)	Background information on wind farm measurements and guidelines; exclude
Ontario Ministry of Health	2011	<i>Open minds, healthy minds: Ontario's comprehensive mental health and addictions strategy</i>		Background information only; exclude
Ontario Ministry of Health	2010	<i>Health, not health care: changing the conversation</i>	2010 Annual Report of the Chief Medical Officer of Health of Ontario and the Legislative Assembly of Ontario	Background information only; exclude
Ontario Ministry of the Environment		Sound level adjustments	Publication NPC-104	Background information only; exclude
Palmer W		Learning from evidence of sound experienced from wind turbines		Commentary/opinion; exclude
Papadopoulos G	2012	Wind turbines and low-frequency noise: implications for human health		Commentary/opinion; exclude
Park J, Robertson J	2009	A portable infrasound generator	Infrasound Laboratory, University of Hawaii, 2009 Acoustical Society of America;	Background information only; exclude

Parkesbourne/Mummel Landscape Guardians Inc.	2012	NSW Planning Guidelines—Wind farms: a resource for the community, applicants and consent authorities (draft)	Submission to the NSW Department of Planning & Infrastructure, March 2012	Guidelines/ regulations; exclude
Pedersen E	2010	Health aspects associated with wind turbine noise: results from three field studies	<i>Noise Control Engineering Journal</i> 2010; 59(1):47–53	Study; include (also identified in the black literature search)
Pedersen E, Hallberg LRM, Persson Waye K	2007	Living in the vicinity of wind turbines: a grounded theory study.	<i>Qualitative Research in Psychology</i> 2007; 4(1):49–63	Study—qualitative design; exclude
Pedersen E, Larsman P	2008	The impact of visual factors on noise annoyance among people living in the vicinity of wind turbines	<i>Journal of Environmental Psychology</i> 2008; 28:379–389	Study; include (also identified in the black literature search)
Pedersen E, Persson Waye K	2004	Perception and annoyance due to wind turbine noise—a dose-response relationship.	<i>Journal of the Acoustical Society of America</i> 2004; 116(6):3460–3470	Study; include (also identified in the black literature search)
Pedersen E, Persson Waye K	2007	Wind turbine noise, annoyance and self-reported health and well-being in different living environments	<i>Occupational and Environmental Medicine</i> 2007; 64(7):480–486	Study; include (also identified in the black literature search)
Pedersen TH, Nielsen KKS	1994	Annoyance by noise from wind turbines	Report no. 150, DELTA Acoustic and Vibration, Lydtekniske Institute, Copenhagen [in Danish]	Language not English; exclude
Persson Waye K	2004	Effects of low-frequency noise on sleep	<i>Noise Health</i> 2004; 6:87–91	Background information on low-frequency noise and sleep; exclude
Persson Waye K, Rylander R	2001	The prevalence of annoyance and effects after long-term exposure to low-frequency noise	<i>Journal of Sound and Vibration</i> 2001; 240(3):483–497	Background information on low-frequency noise and annoyance; exclude
Persson Waye K, Rylander R, Benton S, Leventhall HG	1997	Effects on performance and work quality due to low-frequency ventilation noise	<i>Journal of Sound and Vibration</i> 1997; 205(4):467–474	Background information on noise and work performance; exclude
Persson Waye K, Bengtsson J, Rylander R, Hucklebridge F, Evans P, Chow A	2002	Low-frequency noise enhances cortisol among noise sensitive subjects	<i>Life Sciences</i> 2002; 70:745–758	Background information on health effects of low-frequency noise; exclude
Persson Waye K, Bengtsson J, Kjellberg A, Benton S	2001	Low-frequency noise ‘pollution’ interferes with performance	<i>Noise Health</i> 2001; 4:33–49	Background information on low-frequency noise; exclude
Persson Waye K, Clow A, Edwards S, Hucklebridge F,	2003	Effects of night time low-frequency noise on the cortisol response to awakening and subjective	<i>Life Sciences</i> 2003; 72:863–875	Background information on low-frequency noise and sleep; exclude

and Rylander R		sleep quality		
Philips CV	2011	Properly interpreting the epidemiologic evidence about the health effects of industrial wind turbines on nearby residents	Populi Health Institute, Wayne, PA, USA; <i>Bulletin of Science, Technology & Society</i> 2011; 31:303–315; doi:10.1177/0270467611412554	Background information on interpretation of health effects of wind turbines; exclude
Phillips CV	2011	Submission to the Australian Senate by CV Phillips on ‘the health effects of wind turbines on nearby residents’ re the social and economic impact of rural wind farms, 9 February 2011		Commentary/opinion; exclude
Phipps R	2007	Evidence of Dr Robyn Phipps, In the Matter of Moturimu Wind Farm Application, heard before the Joint Commissioners, 8–26 March, 2007, Palmerston North, NZ		Commentary/opinion; exclude
Pierpont N	2010	Wind turbine syndrome and the brain	Conference paper, First International Symposium on the Global Wind Industry and Adverse Health Effects: Loss of social justice?, Picton, Ontario, Canada, 30 October 30 2010	Background information on wind turbine syndrome; exclude
Pierpont N	2007		Letter to Geoff Leventhall, Consultant in Noise and Vibration and Acoustics, 14 January 2007	Commentary/opinion—letter; exclude
Punch J, James R, Pabst D	2010	Wind turbine noise: what audiologists should know	<i>Audiology Today</i> 2010; July/August issue	Background information on wind turbine noise; exclude
PWC Consulting	2002	Noise proprietary questions for Health Canada	<i>HealthInsider</i> 2002; 7	Background information only; exclude
Radneva R	1997	Studying the effect of acoustic conditions in the living environment of multifamily buildings on inhabitants (Bulg.)	<i>Khig. Zdraveopazvane</i> 1997; 40(3–4):40–44 EMBASE record 1998252323	Background information on built environment acoustics; exclude
Rand RW, Ambrose SE, Krogh CME	2011	Occupational health and industrial wind turbines: a case study	Published online, doi: 10.1177/0270467611417849, <i>Bulletin of Science, Technology & Society</i> 2011; 31:359–362	Commentary/opinion—sound measurements and personal experience of symptoms at an individual home near a turbine; exclude

Rapley B, Bakker H (editors)	2010	Sound, noise, flicker and the human perception of wind farm activity	Atkinson & Rapley Consulting Ltd (Palmerston North, New Zealand), in association with Noise Measurement Services Pty Ltd (NMS) (Brisbane, Australia)	Background information, book requiring payment; exclude
Rideout K, Copes R, Bos C	2010	Wind turbines and health: evidence review	National Collaborating Centre for Environmental Health (Canada)	Background information only; exclude
Rider CV, Dourson M, Hertzberg RC, Mumtaz MM, Price PS, Simmons JE	2012	Incorporating Nonchemical Stressors into Cumulative Risk Assessment	<i>Toxicological Sciences Advance Access</i> ; published 17 February 2012	Background information only; exclude
Robert Koch Institute	2007	Infraschall und tieffrequenter Schall: ein Thema für den umweltbezogenen Gesundheitsschutz in Deutschland? (Subsonic low-frequency sound: a topic for the environmentally related health protection?)	<i>Bundesgesundheitsbl Gesundheitsforsch Gesundheitsschutz</i> 2007; 50:1582–1589	Language not English; exclude
Roberts M, Roberts J	2009	<i>Evaluation of the scientific literature on the health effects associated with wind turbines and low-frequency sound</i>	Prepared for Wisconsin Public Service Commission Docket No. 6630-CE-302	Narrative review; exclude
Salt AN	2004	Acute endolymphatic hydrops generated by exposure of the ear to non-traumatic low-frequency tone	<i>Journal of the Association of Research in Otolaryngology</i> 2004; 5:203–214	Background information on effects of low-frequency sound; exclude
Salt AN	2010	<i>Wind turbines are hazardous to human health</i>	<www.oto2.wustl.edu/cochlea/wind.html> and at <www.windvigilance.com>	Background information on wind turbine infrasound; exclude
Salt AN, Hullar TE	2010	Responses of the ear to low-frequency sounds, infrasound, and wind turbines	<i>Hearing Research</i> 2010; 268(1–2):12–21	Background information on effects of infrasound and low-frequency noise from wind turbines; exclude
Salt AN, Lichtenhan JT	2011	Responses of the inner ear to infrasound	Fourth International Meeting on Wind Turbine Noise, Rome, Italy, 12–14 April 2011	Background information on effects of infrasound; exclude
Salt AN, Lichtenhan JT	2012	Perception-based protection from low-frequency sounds may not be enough	Inter-Noise Congress, 19–22 August 2012, New York City	Background information on effects of low-frequency sound; exclude
Schust M	2004	Effects of low-frequency noise up to 100 Hz	<i>Noise & Health</i> 2004; 6(23):73–85	Background information on effects of low-frequency sound; exclude
Senanayake MP	2002	Noise from power generators: its impact on the	<i>Sri Lanka Journal of Child Health</i>	Background information only; exclude

		health of five children below two years of age	2002; 31:115–117	
Senate, The; Community Affairs Committee	References	2011	<i>The social and economic impact of rural wind farms</i> , June 2011	Background information with no health outcomes; exclude
Sennheiser J		2011	The city and its secret vibrations	Commentary/opinion; exclude
Shepherd D		2012	Wind farms and health: who is fomenting community anxieties?	<i>Medical Journal of Australia</i> 2012; 196(2) Commentary/opinion—letter; exclude
Shepherd D		2010	Wind turbine noise and health in the New Zealand context	Rapley and Bakker (eds) 2010, pp. 15–68 Background information only; exclude
Shepherd D		2010		Submission by Daniel Shepherd, Auckland University of Technology Background information and review; exclude
Shepherd D, Billington R		2011	Mitigating the acoustic impacts of modern technologies: acoustic, health and psychosocial factors informing wind farm placement	<i>Bulletin of Science Technology & Society</i> 2011; 31:389, originally published online 22 August 2011 Background information on acoustic impact of technology; exclude
Shepherd D, Hanning C, Thorne B		2012	Noise: windfarms	Background information on wind farm noise; exclude
Shepherd KP, Hubbard HH		1989	<i>Noise radiation characteristics of the Westinghouse WWG-0600 (600 kW) wind turbine generator</i>	National Aeronautics and Space Administration, TM101576, July 1989 Background information only; exclude
Simonetti T, Chapman S		2012	Is there any disease or symptom NOT caused by wind turbines?	List of symptoms with related weblinks, no additional references to include; exclude
Siponen D		2011	The assessment of low-frequency noise and amplitude modulation of wind turbines	Conference paper, 4th International Meeting on Wind Turbine Noise, Rome, Italy, 12–14 April 2011 Background information on assessment of low-frequency noise from wind turbines; exclude
Smedley ARD, Webb AR, Wilkins AJ		2010	Potential of wind turbines to elicit seizures under various meteorological conditions	<i>Epilepsia</i> 2010; 51(7):1146–1151 Background information of modelling for linking epileptic seizures to turbine shadow flicker; exclude
Society for Wind Vigilance		2010a	<i>Wind energy industry acknowledgement of adverse health effects: an analysis of the American/Canadian Wind Energy Association-sponsored wind turbine sound and health effects: an expert panel review</i> , December 2009	Prepared by the Society for Wind Vigilance, January 2010 Background information only; exclude

Society for Wind Vigilance	2010b	<i>Delay, denial and disappointment: an analysis of the Chief Medical Officer of Health (CMOH) of Ontario's 'The potential health impacts of wind turbines', May 2010</i>	Prepared by the Society for Wind Vigilance, 3 June 2010	Background information and analysis of CMOH of Ontario review; exclude
Sonus Pty Ltd	2010	<i>Wind farms technical paper: environmental noise</i>	Prepared for the Clean Energy Council, November 2010, S3387C6	Background information on wind farm infrasound; exclude
Sonus Pty Ltd	2010	Infrasound measurements from wind farms and other sources		Background information on infrasound; exclude
Standing Senate Committee on Energy, The Environment and Natural Resources	2011	Industrial wind turbines and health: wind turbines can harm humans	The Society for Wind Vigilance	List of abstracts, no additional references to include; exclude
Standing Senate Committee on Energy, The Environment and Natural Resources	2011	Industrial wind turbines and health: wind turbines can harm humans	Presentation, 18 October 2011	Background information on health effects of wind farm noise; exclude
Styles P, Stimpson I, Toon S, England R, Wright M	2005	Microseismic and infrasound monitoring of low-frequency noise and vibrations from windfarms: recommendations on the siting of windfarms in the vicinity of Eskdalemuir, Scotland	Keele University	Guidelines/regulations for wind farm siting; exclude
Suter AH	1991	Noise and its effects	Administrative Conference of the United States	Background information on noise and its impact; exclude
Swinbanks MA	2012	Infrasound from wind turbines	Letter from Malcolm Swinbanks	Commentary/opinion—letter; exclude
Swinbanks MA	2011	The audibility of low-frequency wind turbine noise	Fourth International Meeting on Wind Turbine Noise, Rome, Italy, 12–14 April 2011	Background information on low-frequency noise; exclude
Swinbanks MA	2012	Numerical simulation of infrasound perception, with reference to prior reported laboratory effects	Inter-Noise Congress 2012, 19–22 August 2012, New York City	Background information on infrasound perception; exclude
Swinbanks MA	2012	Numerical simulation of infrasound perception, with reference to prior reported laboratory effects.	Power Point presentation at Inter-Noise Congress, 19–22 August 2012, New York City	Background information on infrasound perception; exclude
Swinbanks MA	2012	Numerical simulation of infrasound perception, with reference to prior reported laboratory	Paper presented to the First International Symposium on	Background information on infrasound perception; exclude

		effects	Adverse Health Effects from Wind Turbines, Picton, Ontario, 29–31 October 2010	
Swinbanks MA	2011	Wind turbines: low-frequency noise, infrasound & health effects	Scottish National Wind Conference, Friday 11 November 2011, Prestwick, Scotland	Background information on wind turbine noise; exclude
Tamura H, Ohgami N, Yajima I, Iida M, Ohgami K, Fujii N, Itabe H, Kusudo T, Yamashita H, Kato M	2012	Chronic exposure to low-frequency noise at moderate levels causes impaired balance in mice	PLOS ONE: research article, published 29 June 2012; doi: 10.1371/journal.pone.0039807	Study—unsuitable population; exclude
Tharpaland International Retreat Centre	2003	Effects of windfarms on meditative retreaters: a human impact assessment (Tharpaland International Retreat Centre)		Commentary/opinion regarding visitors to an area proximal to a wind farm; exclude
Tharpaland International Retreat Centre	2004	An assessment of infrasound and other possible causes of the adverse effects of windfarms		Background information on possible cause of health effects near wind farms; exclude
Tharpaland International Retreat Centre		Executive summary: Three windfarm studies and an assessment of infrasound	Submission by Tharpaland International Retreat Centre (accompanied by additional documents)	Background information on health effects of wind farms; exclude
The Acoustic Group Pty Ltd	2012	Peer review of environmental noise assessment: Collector Wind Farm 42.5006.R1:ZSC	Prepared for Friends of Collector, C/- Hegarty and Elmgreen	Background information on noise effects, opinion paper; exclude
The Acoustic Group Pty Ltd	2012	Annexure A	Prepared for Friends of Collector, C/- Hegarty and Elmgreen	Background information on noise and wind farms; exclude
The Acoustic Group Pty Ltd	2011	Peer review of acoustic assessment: Flyers Creek Wind Farm 41.4963.R1A:ZSC	Prepared for Flyers Creek Wind Turbine Awareness Group Inc., 15 December 2011	Background information on acoustic assessment; exclude
The Regional Municipality of Durham	2010	Correspondence advising of the resolution passed by the city of Oshawa: A. Endorsing the city of Pickering's motion requesting the region of Durham retain an integrity commissioner; B. Advising that the city of Oshawa will accept its share of the cost on per-use basis		Commentary/opinion—letter; exclude
The Regional Municipality of Durham	2010	The potential health impact of wind turbines	Report No. 2010-MOH-18	Narrative review; exclude
Thorne R	2011	The problem with 'noise numbers' for wind farm	<i>Bulletin of Science, Technology</i>	Narrative review; exclude

		noise assessment	<i>and Society</i> 2011; 31(4):262–290	
Thorne R	2010	Hearing and personal response to sound	Rapley and Bakker (eds) 2010, pp. 69–78	Background information only; exclude
Thorne R	2010	Health, wellbeing, annoyance and amenity	Rapley and Bakker (eds) 2010, pp. 93–101	Background information only; exclude
Thorne R	2010	Synopsis of assessing intrusive noise and low-amplitude sound	Rapley and Bakker (eds) 2010, pp. 111–125	Background information only; exclude
Thorne R	2010	Wind farms: the potential for annoyance	Rapley and Bakker (eds) 2010, pp. 127–133	Background information only; exclude
Thorne R	2010f	Noise from wind turbines	Rapley and Bakker (eds) 2010, pp. 217–224	Background information only; exclude
Thorne R	2011	Wind farms in a rural environment and potential for serious harm to human health due to noise	Submission to the Senate Community Affairs Committee, 'Inquiry into the social and economic impacts of rural wind farms', 30 January 2011, rev.1	Commentary/opinion paper; exclude
Thorne R, Rapley B, Heilig J	2010	Waubra Wind Farm Noise Impact Assessment for Mr & Mrs Dean; Report no. 1537, Rev. 1, July 2010		Background information on wind turbine noise assessment, particularly at the Waubra Wind Farm; exclude
Todd N	2001	Evidence for a behavioural significance of saccular acoustic sensitivity in humans	<i>Journal of the Acoustical Society of America</i> 2001; 110(1):380–390.	Background information only; exclude
Todd NP, Rosengren SM, Colebatch JG	2008	Tuning and sensitivity of the human vestibular system to low-frequency vibration	Faculty of Life Science, University of Manchester, UK; <i>Neuroscience Letters</i> 2008; 444(1):36–41 Epub 8 August 2008	Background information only; exclude
Tognato C, Spoehr J	2012	<i>The energy to engage: wind farm development and community engagement in Australia</i>	Report prepared for the Institute for Mineral and Energy Resources, The University of Adelaide	Background information on community engagement and wind farms; exclude
Turnbull C, Turner J, Webb D	2012	Infrasound measurement results in Australia near wind turbines and other infrasound sources	Acoustics Australia (2012) Vol. 40, No. 1	Background information—infrasound measurements, no health outcomes; exclude
UK Noise Association	2006	Location, location, location: an investigation into wind farms and noise		Narrative review, personal testimonies; exclude

University of Gothenburg	2008	<i>Wind farm perception: visual and acoustic impact of wind turbine farms on residents</i> ; final report	FP6-2005-Science-and-Society-20; Specific Support Action, Project no. 044628	Duplicate study/data—duplication of data from included study (van den Berg et al., see below); exclude
Van den Berg GP	2005	The beat is getting stronger: the effect of atmospheric stability on low-frequency modulated sound by wind turbines	<i>Journal of Low Frequency Noise, Vibration, and Active Control</i> 2005; 24(1):1–24	Background information on wind turbine noise measurement; exclude
Van den Berg GP	2003	Effects of the wind profile at night on wind turbine sound	<i>Journal of Sound and Vibration</i> doi:10.1016/j.jsv.2003.09.050	Background information on wind turbine noise measurement; exclude
Van den Berg GP	2001	Do wind turbines produce significant low-frequency sound levels?	Conference paper: 11th Meeting on Low Frequency Noise and Vibration and its Control, August 30 – September 1, Maastricht, Holland	Background information on wind turbine low-frequency noise; exclude
Van den Berg F, Pedersen E, Bouma J, Bakker R		Visual and acoustic impact of wind turbine farms on residents	< https://www.wind-watch.org/documents/visual-and-acoustic-impact-of-wind-turbine-farms-on-residents/ >	Study; include (provides additional information to the study by Bakker et al. (2012) identified in the black literature search)
Wang Z	2011	Evaluation of wind farm noise policies in South Australia: a case study of Waterloo Wind Farm	Case study	Study—does not include any comparative analysis, includes the same population as Morris's study (residents living near Waterloo Wind Farm); exclude
Watts CJ	2011	Submission to Department of Planning and Infrastructure on proposed Flyers Creek Wind Farm, Blayney local government area	Flyers Creek Wind Turbine Awareness Group Inc.	Commentary opinion—response to the proposal for wind farm at Flyers Creek, NSW; exclude
Watts CJ	2011	Flyers Creek submission: personal letters, 15 December 2011		Commentary/opinion—letters; exclude
Watts AC, Watts CJ	2012	Draft NSW Planning Guidelines Wind Farms submission, NSW Department of Planning and Infrastructure		Background information on wind farm planning guidelines; exclude
Watts AC, Watts CJ	2012	Collector Wind Farm MP 10_0156; Proposed Collector Wind Farm, Upper Lachlan local government area (Ratch Australia Corporation): noise and health		Background information on wind farm noise and effects, particularly the Waubra Wind Farm; exclude
Waubra Foundation	2012	Submission by Dr Sarah Laurie, CEO Waubra Foundation		Commentary/opinion—letter; exclude

Waubra Foundation	2012	Wind turbine acoustic pollution assessment requirements		Commentary/opinion; exclude
Waubra Foundation	2011	Brief summary of field data collected from residents and visitors adversely impacted by infrasound and low-frequency noise (ILFN) emissions from a variety of sources in Australia		Study—qualitative design; exclude
Waubra Foundation	2012	Collector Wind Farm development	Hon Brad Hazzard, Director General, NSW Department of Planning, individuals responsible for the decision re the Collector Wind Development	Not found by cut-off date; exclude
Wind Watch		Wind energy facilitates local law, town of Litchfield, New York		Commentary/opinion; exclude
Wolsink M, Sprengers M	1993	Wind turbine noise: a new environmental threat?	<i>Proceedings of the Sixth International Congress on the Biological Effects of Noise</i> , ICBEN, Nice, France, 1993; 2:235–238	Background information only; exclude
Wolsink M, Sprengers M, Keuper A, Pedersen TH, Westra CA	1993	Annoyance from wind turbine noise on sixteen sites in three countries.	<i>Proceedings of the European Community Wind Energy Conference</i> , Lubeck, Travemunde, 1993; 273–276	Not found by cut-off date; exclude
World Health Organization	1990	<i>Guidelines for community noise</i> , ed. by Berglund, B, Lindvall, T, Schwela, DH, World Health Organization, 1999		Guidelines/regulations for acceptable noise levels; exclude
World Health Organization		<i>Constitution of the World Health Organization</i>		Background only; exclude
World Health Organization	2003	WHO definition of health		Background only; exclude
World Health Organization	1998	Health promotion glossary		Background only; exclude
World Health Organization	2008	<i>Closing the gap in a generation: health equity through action on the social determinants of health</i>		Background only; exclude
World Health Organization	2009	<i>Noise and health</i>	Copy of email correspondence	Background information on health effects of noise; exclude
World Health Organization	2011	<i>Occupational and community noise</i>	Fact sheet no. 258	Background information on health effects of noise; exclude
World Health Organization	2010	<i>Mental health: strengthening our response</i>	Media centre fact sheet no. 220,	Background only; exclude

September 2010

World Health Organization Europe		2009	<i>Night Noise Guidelines for Europe</i> , World Health Organization, Copenhagen, 2009		Guidelines/regulations for acceptable noise levels; exclude
World Organization, Health and Welfare Canada	Health	1986	<i>Ottawa Charter for Health Promotion</i>		Background information only; exclude
World Organization, office for Europe	Health Regional	2012	<i>Environmental health in equities in Europe</i>		Background information only; exclude
World Organization, office for Europe	Health Regional	2004	WHO LARES final report: <i>Noise effects and morbidity</i>		Background information on health effects of noise; exclude
World Organization, office for Europe	Health Regional	2004	WHO LARES final report: <i>Noise effects and morbidity</i>	Copy of website page	Background information on health effects of noise; exclude
World Organization, office for Europe	Health Regional	2007	<i>Large analysis and review of European housing and health status (LARES): preliminary overview</i>		Background information only; exclude
Yang Y		2009	Gene and protein expression patterns in the rat inner ear during ototoxicity and otoprotection	Dissertation	Study—unsuitable population; exclude

Wind Turbines: Do they affect our health?

Robert J. McCunney, MD

Wind Turbines:

- Operation of a wind turbine: major exposure concern: Noise
- Noise is both
 - (1) mechanical-from gear box and control mechanisms and
 - (2) aerodynamic-operation of the blades

Noise Levels in decibels (dBA**)

■ Jet Engines	140
■ Rock Band	110
■ Tractor/power saw	100
■ Lawn mower at 3 feet	95
■ Vacuum cleaner at 3 feet	85
■ Busy restaurant	78
■ Speech range:	50-70
■ Whisper	30
■ Area near wind turbine (300 meters)	35-45*

* See Environmental Impacts of Wind Energy Projects, NRC (2007)

- ***Risk of hearing impairment: exposure > 80 dB (A) for many years***

Wind Turbines and sound

- According to the National Research Council, sound power from a single wind turbine "is usually around 90-105 dB (A); such a turbine creates a sound pressure of 50-60 dB (A) at a distance of 40 meters (this is about the same level as quiet conversational speech).
- "Noise (sound pressure) levels from an onshore wind project are typically in the 35-45 dB (A) range at a distance of about 300 meters." (NRC)

Sound Frequencies and Hearing

- Speech frequency 500 Hz -20,000 Hz
- Low frequency: 20-250 Hz
- Infra sound < 20 Hz

Three kinds of sound emitted by wind turbines that have received some attention are:

1. Infrasound
2. Low frequency sound of approximately 10-200 Hz
3. Fluctuating aerodynamic “swish” from the turbine blades which is in the mid-frequency range, approximately 500-1000 Hz.

Infra Sound and Hearing Perception

Freq Hz	4	8	10	16	20
Noise Level (dB SPL)	107	100	97	88	79

Infra Sound and Hearing Perception

- The noise level (dB) refers to the loudness of the sound necessary for it to be heard at the respective frequency of the sound.
- Wind turbines: ~ infrasound emitted from wind turbines is at a level of 50 to 70 dB, sometimes higher, but well below the audible threshold for infrasound.

Wind Turbines: Are there health effects?

- Due to the long wave lengths of low frequency noise, it can travel long distances and pass through walls and windows with little attenuation.
- There is no evidence for physiological effects from infrasound or low frequency sound at the levels generated from Wind Turbines.
- There can, however, be effects from the sounds becoming audible, but these are similar to effects from other audible sounds

Literature Review

Point: address peer reviewed studies of
“wind turbines and health’ via Pub MED
search

Wind Turbines and health:

3 Cross sectional studies of people living in
vicinity of wind turbines in the Netherlands
and Sweden.

Pedersen et al, 2009

- A sample of 1948 people (among > 70,000 adults) living within 2.5 km of a wind turbine in the Netherlands
- Sound level measurements available
- Questionnaire completed

Pedersen et al, 2009

Sound level; dB(A)	30-35	35-40	40-45	>45
Number of people	213	159	93	65
Very annoyed	1 (0.5%)	4 (2.5%)	10 (11%)	2 (3%)

Pedersen et al, 2009

- Authors noted that the % of people who reported annoyance from wind turbine sound appeared to lie between aircraft noise and shunting yards
- Correlation noted- as in other studies- of a link between attitude towards wind turbines and reporting annoyance

Pedersen, 2007

- Evaluation of 754 (among 3471 eligible) people in Sweden

Methods:

1. Questionnaire
2. Sound measurement calculations
3. Distances: 605-1014 meters between homes and turbines

Pedersen, 2007

Results

@ 35-37 db < 5% very annoyed

@ > 40 dB, ~ 15% very annoyed

Strongest associations reported:

Odds ratio (OR) 13.4 (95% CI: 6-30) based on attitude towards wind turbines

OR 14.4 (95% CI: 6-32) attitude RE: Visual impact of turbines

Thus, those who had unfavorable attitude towards WT were over 13 times more likely to be “annoyed”.

Pedersen, 2004

- 351 people in Sweden in 5 domestic areas
- Wind turbines: 600-660 kW
- Frequency analysis: @ Hz < 200 (ie low frequency sound) sound levels ranged from the mid 30s dB to mid 40s dB with a spike of 48 dB at ~ 26 Hz.
- Distances from homes to wind turbines: 150-1199 meters

Pedersen, 2004

- Among 132 people in the 32.5-35 dB range, at a distance of 550-599 meters, 6% reported being very annoyed
- Attitude towards wind turbines was the strongest factor associated with annoyance

Summary of wind turbine environmental studies

Based on the similarity of results of the studies of residents in the vicinity of wind turbines in Sweden and the Netherlands, a number of conclusions can be drawn:

- A small percentage of people report being very annoyed by the sound from wind turbines at levels < 35 dB
- As the noise levels increase, more people report being annoyed
- The perception of "annoyance" from the sound of wind turbines is strongly related to attitudes toward wind turbines. The people who are most likely to be "annoyed" are those who do not like wind turbines

Infrasound & Low Frequency Noise

- No link between LFN from wind turbines and health effects
- FDA approves infra sound for therapeutic massage at 70 dB

Low frequency sound

Danish Study 2008

- Wind turbines do not emit audible infra sound.
- Other noise sources, such as road traffic, emit low frequencies of higher levels.
- There is an approximate 5-15 dB (A) attenuation of noise from outdoors to indoors with the windows shut.
- The percentage of people annoyed by wind turbine noise at $< 40\text{dB (A)}$ is about 5%.

Low frequency sound

British Study 2006

- Low frequency noise associated with road traffic was greater than sound from neighboring wind farms
- Infrasound associated with modern wind turbines will not be injurious to the health of a wind farm neighbor
- Measurements of infrasound of modern wind farms at distances of 200 meters were between 25 and 40 dB below perception thresholds.
- The authors also referred to a World Health Organization report that stated: "**There is no reliable evidence that infra sounds below the hearing threshold produce physiological or psychological effects.**"

Low frequency sound

British Study 2006 (Cont'd)

- The common cause of complaint was not associated with low frequency noise but with occasional audible modulation of aerodynamic noise, mostly at night.
- “Of the 126 wind farms operating in the UK, 5 reported low frequency noise problems. Therefore such complaints are the exception rather than a general problem for wind farms.” (Hayes McKenzie, 2006).

Low frequency sound

USA Study 2010

- 15 wind turbines

The results indicated:

- infrasound is inaudible to even the most sensitive people 305 meters (1,000 feet) from the wind turbines. Low frequency sound above 40 Hz may be audible depending on background sound levels
- At maximum noise at a distance more than 305 meters (1,000 feet) from the nearest residence, wind turbines do not pose a low frequency noise or infrasound problem. "At this distance the wind farms met ANSI/ASA S12.2 indoor levels for low frequency sound for bedrooms, classrooms and hospitals ding on background sound levels

LFN and health effects

- Health related effects of living in the vicinity of wind turbines and corresponding exposure to low frequency sound have been evaluated in the Netherlands (van den Berg, 2008).
- No link between noise levels and risk of diabetes, hypertension, tinnitus and cardiovascular disease was noted. To the contrary, the illnesses assessed were more common at the lower sound levels than the higher sound levels which indicated no link between noise and the illnesses assessed

Infra sound and health

- In Apollo space program experiments, subjects were exposed to between 120 and 140 dB of LFN without harmful effects.
- U.S. space program :studies indicate that 24-hour exposures to 120 to 130 dB are tolerable below 20 Hz, the upper limit of infrasound.
- Modern wind turbines produce sound that is assessed as infrasound at typical levels of 50 to 70 dB, below the hearing threshold at those frequencies (Jakobsen, 2004), who concluded that infrasound from wind turbines does not present a health concern.

Infra sound and health

- Heart tones: 1-2 Hz
- Lung sounds: 5-35 dB at 150-600 Hz
- “A few meters from the device, windmill noise in the infra sound range becomes rapidly inaudible. This infrasound has no effect on human health. Fears regarding windmill-induced infra sound are thus groundless. Infrasound production by windmills has been well studied and the levels are without risk to humans.”
- French National Academy of Medicine, 2006

Low frequency sound

- Research with low frequencies has shown that an audible low frequency sound does not normally become objectionable until it is 10 to 15 dB above hearing threshold (Inukai et al., 2000; Yamada, 1983).

Wind Turbine Syndrome

- **Hypothesis**: low frequency sound and corresponding vibration adversely affects health
- As of 5/2/10 not published in peer reviewed scientific journal (PubMed search)
- not a recognized diagnosis in the medical community.
- no unique symptoms or combination thereof that would lead to a specific “disease”.
- Symptoms in some people in the context of exposure to wind turbines are likely associated with annoyance

Wind Turbine Syndrome

- Low-level sounds from outside the body do not cause a high enough excitation within the body to exceed the internal body sounds
- The similarity between symptoms of noise annoyance and those of the "Wind Turbine Syndrome" indicates that this "diagnosis" is not a pathophysiological effect, but an example of the well-known stress effects of exposure to noise-virtually any type- displayed by a small proportion of the population.

“Wind Turbine Syndrome”

“Wind Turbine Syndrome” appears based on two hypotheses

- Low levels of airborne infrasound from Wind Turbines, at 1 – 2Hz, directly affect the vestibular system, and
- Low levels of airborne infrasound from Wind Turbines at 4-8Hz enter the lungs via the mouth and then vibrate the diaphragm, which transmits vibration to the viscera. (Internal organs of the body)

“vibroacoustic disease: Interpreting scientific literature

- In the case of wind turbine noise and its hypothetical relationships to “wind turbine syndrome” and “vibroacoustic disease” (VAD), we have only the weakest type of evidence – case series, from only a single investigator. These reports can suggest hypotheses – for further research but do not demonstrate causal connections

“vibroacoustic disease”

- A review of PubMed under the search term "vibroacaoustic disease" indicated 36 references, all but two of which originated with the same Portuguese group noted earlier. It is unclear why the rest of the academic world does not appear to have addressed the vibro-acoustic disease concept introduced by the Portuguese team.

Interpreting scientific literature

- In the case of wind turbine noise and its hypothetical relationships to “wind turbine syndrome” and vibro-acoustic disease, no case-control, cohort or longitudinal studies have been published. In fact, only the weakest type of scientific evidence—case series—is available

Conclusions

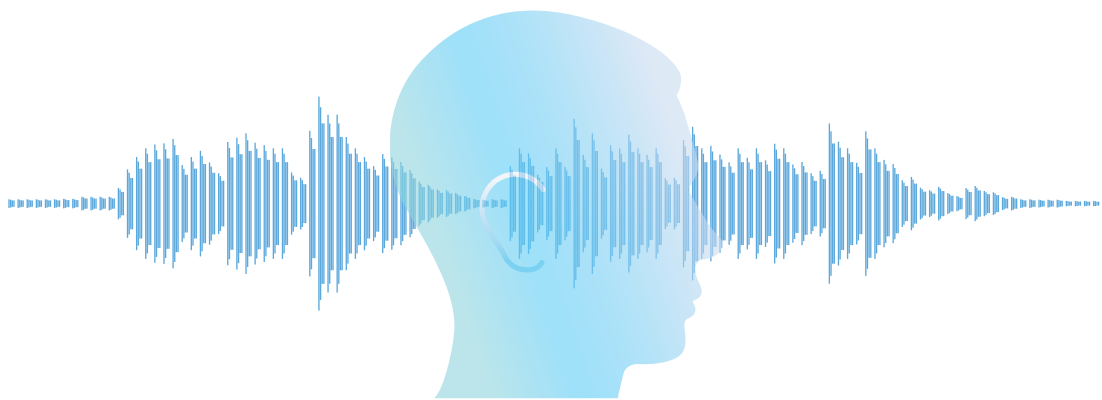
- 1. Noise from wind turbines does not pose a risk of hearing loss or any other direct adverse health effect.
- 2. Some people may become annoyed from the sound from wind turbines but this is not a disease.
- 3. The major cause of concern from wind turbine noise is the fluctuating nature of noise. Some find this noise annoying, a reaction that depends primarily on personal characteristics as apposed to the intensity of the noise level.
- 4. Sub audible low frequency noise and infra sound from wind turbines do not present a risk to health.
- 5. Wind Turbine Syndrome is neither a new disease or accepted medical diagnosis. Symptoms reflect noise annoyance.



World Health
Organization

REGIONAL OFFICE FOR Europe

ENVIRONMENTAL **NOISE** GUIDELINES for the European Region



Abstract

Noise is an important public health issue. It has negative impacts on human health and well-being and is a growing concern. The WHO Regional Office for Europe has developed these guidelines, based on the growing understanding of these health impacts of exposure to environmental noise. The main purpose of these guidelines is to provide recommendations for protecting human health from exposure to environmental noise originating from various sources: transportation (road traffic, railway and aircraft) noise, wind turbine noise and leisure noise. They provide robust public health advice underpinned by evidence, which is essential to drive policy action that will protect communities from the adverse effects of noise. The guidelines are published by the WHO Regional Office for Europe. In terms of their health implications, the recommended exposure levels can be considered applicable in other regions and suitable for a global audience.

Keyword

NOISE – ADVERSE EFFECTS, PREVENTION AND CONTROL

ENVIRONMENTAL EXPOSURE – ADVERSE EFFECTS, PREVENTION AND CONTROL

GUIDELINES

EUROPE

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ISBN 978 92 890 5356 3

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Environmental Noise Guidelines for the European Region

Contents

Figures	iv
Boxes	iv
Tables	v
Foreword.....	vii
Acknowledgements.....	viii
Abbreviations.....	ix
Glossary of acoustic terms	x
Executive summary	xiii
Objectives.....	xiii
Methods used to develop the guidelines	xiii
Noise indicators	xiv
Recommendations.....	xv
Target audience	xviii
1. Introduction	1
1.1 The public health burden from environmental noise.....	1
1.2 The environmental noise policy context in the EU.....	2
1.3 Perceptions of environmental noise in the WHO European Region	4
1.4 Target audience	5
2. Development of guidelines	7
2.1 Overview.....	7
2.2 Scope of the guidelines.....	7
2.3 Evidence base	10
2.4 From evidence to recommendations	16
2.5 Individuals and partners involved in the guideline development process	25
2.6 Previously published WHO guidelines on environmental noise.....	26
3. Recommendations	29
3.1 Road traffic noise.....	30
3.2 Railway noise.....	49
3.3 Aircraft noise.....	61
3.4 Wind turbine noise.....	77
3.5 Leisure noise	87
3.6 Interim targets.....	97

4. Implications for research	99
4.1 Implications for research on health impacts from transportation noise.....	99
4.2 Implications for research on health impacts from wind turbine noise	100
4.3 Implications for research on health impacts from leisure noise.....	101
4.4 Implications for research on effectiveness of interventions to reduce exposure and/or improve public health	102
5. Implementation of the guidelines	105
5.1 Introduction	105
5.2 Guiding principles	105
5.3 Assessment of national needs and capacity-building	106
5.4 Usefulness of guidelines for target audiences.....	107
5.5 Methodological guidance for health risk assessment of environmental noise	108
5.6 Route to implementation: policy, collaboration and the role of the health sector	110
5.7 Monitoring and evaluation: assessing the impact of the guidelines	111
5.8 Updating the guidelines	111
References.....	113
Annexes	141
Annex 1. Steering, advisory and external review groups.....	141
Annex 2. Systematic reviews and background documents used in preparation of the guidelines.....	147
Annex 3. Summary of conflict of interest management.....	149
Annex 4. Detailed overview of the evidence of important health outcomes	150

Figures

Fig. 1. The association between exposure to road traffic noise (L_{den}) and the incidence of IHD.....	33
Fig. 2. The association between exposure to road traffic noise (L_{den}) and the prevalence of IHD.....	34
Fig. 3. The association between exposure to road traffic noise (L_{den}) and mortality from IHD.....	35
Fig. 4. The association between exposure to road traffic noise (L_{den}) and hypertension.....	36
Fig. 5. The association between exposure to road traffic noise (L_{den}) and stroke.....	37
Fig. 6. Scatterplot and quadratic regression of the relationship between road traffic noise (L_{den}) and annoyance (in %HA)	39
Fig. 7. The association between exposure to railway noise (L_{den}) and the prevalence of IHD.	52
Fig. 8. The association between exposure to railway noise (L_{den}) and hypertension.....	53
Fig. 9. Scatterplot and quadratic regression of the relationship between railway noise (L_{den}) and annoyance (in %HA)	54
Fig. 10. The association between exposure to aircraft noise (L_{den}) and IHD.....	65
Fig. 11. The association between exposure to aircraft noise (L_{den}) and hypertension in cross-sectional and cohort studies.	66
Fig. 12. The association between exposure to aircraft noise (L_{den}) and stroke.....	67
Fig. 13. Scatterplot and quadratic regression of the relationship between aircraft noise (L_{den}) and annoyance (%HA)	68
Fig. 14. The association between exposure to wind turbine noise (sound pressure level in dB) and hypertension.....	80
Fig. 15. The association between exposure to wind turbine noise (sound pressure level in dB) and self-reported cardiovascular disease.....	81
Fig. 16. Overlay of the two wind turbine annoyance graphs	82

Boxes

Box 1 GRADE interpretations of quality of evidence.....	16
Box 2 Parameters determining the strength of a recommendation.....	24

Tables

Table 1. Inclusion and exclusion criteria for evidence reviews for health effects of environmental noise	12
Table 2. Types of noise interventions	13
Table 3. Critical health outcomes, outcome measures identified and justifications for selection .	18
Table 4. Important health outcomes and health outcome measures reviewed	19
Table 5. Priority health outcomes and relevant risk increases for setting the guideline levels	21
Table 6. Average exposure levels (L_{den}) for priority health outcomes from road traffic noise	30
Table 7. Night-time exposure levels (L_{night}) for priority health outcomes from road traffic noise	31
Table 8. PICOS/PECCOS scheme of critical health outcomes for exposure to road traffic noise.....	32
Table 9. Summary of findings for health effects from exposure to road traffic noise (L_{den})	32
Table 10. The association between exposure to road traffic noise (L_{night}) and sleep disturbance (%HSD)	40
Table 11. Summary of findings for health effects from exposure to road traffic noise (L_{night})	41
Table 12. The association between exposure to road traffic noise (L_{night}) and sleep disturbance (%HSD)	41
Table 13. PICOS/PECCOS scheme of the effectiveness of interventions for exposure to road traffic noise	42
Table 14. Summary of findings for road traffic noise interventions by health outcome.....	43
Table 15. Summary of the assessment of the strength of the road traffic noise recommendations.....	48
Table 16. Average exposure levels (L_{den}) for priority health outcomes from railway noise	49
Table 17. Night-time exposure levels (L_{night}) for priority health outcomes from railway noise	50
Table 18. PICOS/PECCOS scheme of critical health outcomes for exposure to railway noise	51
Table 19. Summary of findings for health effects from exposure to railway noise (L_{den})	51
Table 20. The association between exposure to railway noise (L_{den}) and annoyance (%HA)	55
Table 21. Summary of findings for health effects from exposure to railway noise (L_{night})	56
Table 22. The association between exposure to railway noise (L_{night}) and sleep disturbance (%HSD).....	56
Table 23. PICOS/PECCOS scheme of the effectiveness of interventions for exposure to railway noise	57
Table 24. Summary of findings for railway noise interventions by health outcome.....	57
Table 25. Summary of the assessment of the strength of the recommendation	60
Table 26. Average exposure levels (L_{den}) for priority health outcomes from aircraft noise	61
Table 27. Night-time exposure levels (L_{night}) for priority health outcomes from aircraft noise.....	62

Table 28. PICOS/PECCOS scheme of critical health outcomes for exposure to aircraft noise.....	63
Table 29. Summary of findings for health effects from exposure to aircraft noise (L_{den})	64
Table 30. The association between exposure to aircraft noise (L_{den}) and annoyance (%HA)	69
Table 31. Summary of findings for health effects from exposure to aircraft noise (L_{night})	70
Table 32. The association between exposure to aircraft noise (L_{night}) and sleep disturbance (%HSD).....	70
Table 33. PICOS/PECCOS scheme of the effectiveness of interventions for exposure to aircraft noise.....	71
Table 34. Summary of findings for aircraft noise interventions by health outcome.....	72
Table 35. Summary of the assessment of the strength of the recommendation	76
Table 36. Average exposure levels (L_{den}) for priority health outcomes from wind turbine noise.....	77
Table 37. Night-time exposure levels (L_{night}) for priority health outcomes from wind turbine noise.....	78
Table 38. PICOS/PECCOS scheme of critical health outcomes for exposure to wind turbine noise.....	79
Table 39. Summary of findings for health effects from exposure to wind turbine noise (L_{den}).....	79
Table 40. Summary of findings for health effects from exposure to wind turbine noise (L_{night}).....	83
Table 41. PICOS/PECCOS scheme of the effectiveness of interventions for exposure to wind turbine noise	83
Table 42. Summary of the assessment of the strength of the recommendation	86
Table 43. Average exposure levels ($L_{Aeq,24h}$) for priority health outcomes from leisure noise.....	87
Table 44. Night-time exposure levels (L_{night}) for priority health outcomes from leisure noise	88
Table 45. PICOS/PECCOS scheme of critical health outcomes for exposure to leisure noise	89
Table 46. Summary of findings for health effects from exposure to leisure noise ($L_{Aeq,24h}$).....	90
Table 47. PICOS/PECCOS scheme of the effectiveness of interventions for exposure to leisure noise.....	92
Table 48. Summary of findings for interventions for leisure noise	92
Table 49. Combination of hourly exposure and number of hours per week to arrive at a yearly average L_{Aeq}	96
Table 50. Summary of the assessment of the strength of the recommendation	97
Table 51. Implications for research on health impacts from transportation noise (air, rail, road)	99
Table 52. Recommendation for research addressing the exposure–response relationship	100
Table 53. Implications for research on health impacts from wind turbine noise	100
Table 54. Implications for research on health impacts from leisure noise	101
Table 55. Implications for research on effectiveness of interventions to reduce exposure and/or improve public health.....	103

Foreword

Noise is one of the most important environmental risks to health and continues to be a growing concern among policy-makers and the public alike. Based on the assessment threshold specified in the Environmental Noise Directive of the European Union (EU), at least 100 million people in the EU are affected by road traffic noise, and in western Europe alone at least 1.6 million healthy years of life are lost as a result of road traffic noise.

At the request of Member States at the Fifth Ministerial Conference on Environment and Health in Parma, Italy, in March 2010, the WHO Regional Office for Europe has developed these guidelines, based on the growing understanding of the health impacts of exposure to environmental noise. They provide robust public health advice, which is essential to drive policy action that will protect communities from the adverse effects of noise.

These WHO guidelines – the first of their kind globally – provide recommendations for protecting human health from exposure to environmental noise originating from various sources. They not only offer robust public health advice but also serve as a solid basis for future updates, given the growing recognition of the problem and the rapid advances in research on the health impacts of noise. The comprehensive process of developing the guidelines has followed a rigorous methodology; their recommendations are based on systematic reviews of evidence that consider more health outcomes of noise exposure than ever before. Through their potential to influence urban, transport and energy policies, these guidelines contribute to the 2030 Agenda for Sustainable Development and support WHO's vision of creating resilient communities and supportive environments in the European Region.

Following the publication of WHO's community noise guidelines in 1999 and night noise guidelines for Europe in 2009, these latest guidelines represent the next evolutionary step, taking advantage of the growing diversity and quality standards in this research domain. Comprehensive and robust, and underpinned by evidence, they will serve as a sound basis for action. While these guidelines focus on the WHO European Region and provide policy guidance to Member States that is compatible with the noise indicators used in the EU's Environmental Noise Directive, they still have global relevance. Indeed, a large body of the evidence underpinning the recommendations was derived not only from noise effect studies in Europe but also from research in other parts of the world – mainly in Asia, Australia and the United States of America.

I am proud to present these guidelines as another leading example of the normative work undertaken in our Region in the area of environment and health. On behalf of the WHO Regional Office for Europe and our European Centre for Environment and Health in Bonn, Germany, which coordinated the development of the guidelines, I would like to express my gratitude to the large network of experts, partners, colleagues and consultants who have contributed to this excellent publication. I would also like to thank Switzerland and Germany for providing financial support to this complex project, and look forward to following the influence of the guidelines on policy and research in the years to come.

Dr Zsuzsanna Jakab
WHO Regional Director for Europe

Acknowledgements

The WHO Regional Office for Europe thanks all members of the Steering Group, Guideline Development Group, Systematic Review Team and External Review Group for their invaluable contributions in the guidelines development process.

The WHO Regional Office for Europe, through its European Centre for Environment and Health, coordinated the development of these guidelines. The project was coordinated by Marie-Eve Héroux and Dorota Jarosinska, under the overall supervision of Elizabet Paunovic, Head of the European Centre for Environment and Health.

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The WHO Regional Office for Europe gratefully acknowledges funding and in-kind contributions from the Swiss Federal Office for the Environment; the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety; and the German Environment Agency for this activity.

Abbreviations

%HA	percentage of the population “highly annoyed”
%HSD	percentage of the population “highly sleep-disturbed”
BMI	body mass index
CI	confidence interval
CNG	WHO guidelines for community noise
DALY	disability-adjusted life-year
dB	decibel
DW	disability weight
EC	European Commission
EEA	European Environment Agency
END	European Union Directive 2002/49/EC relating to the assessment and management of environmental noise (Environmental Noise Directive)
ERF	exposure–response function
EU	European Union
GDG	Guideline Development Group
GRADE	Grading of Recommendations Assessment Development and Evaluation
ICBEN	International Commission on Biological Effects of Noise
IHD	ischaemic heart disease
JRC	Joint Research Centre [of the European Commission]
mmHg	millimeters of mercury
NNG	WHO night noise guidelines for Europe
OR	odds ratio
PECCOS	population, exposure, comparator, confounder, outcome and study [framework]
PICOS	population, intervention, comparator, outcome and study [framework]
PLD	personal listening device
RANCH	Road traffic and aircraft noise exposure and children’s cognition and health [study]
RCT	randomized control trial
RR	relative risk
SCENIHR	Scientific Committee on Emerging and Newly Identified Hazards and Risk

Glossary of acoustic terms

A-weighting	A frequency-dependent correction that is applied to a measured or calculated sound of moderate intensity to mimic the varying sensitivity of the ear to sound for different frequencies
C-weighting	A frequency-dependent correction that is applied to a measured or calculated sound of moderate intensity to mimic the varying sensitivity of the ear to sound for different frequencies – C-weighting is usually used for peak measurements
FAST	Fast response has a time constant of 125 milliseconds on a sound level meter
$L_{Aeq,T}$	A-weighted, equivalent continuous sound pressure level during a stated time interval starting at t_1 and ending at t_2 , expressed in decibels (dB), at a given point in space ¹
$L_{A,max}$	Maximum time-weighted and A-weighted sound pressure level within a stated time interval starting at t_1 and ending at t_2 , expressed in dB ¹
L_{AF}	A-weighted sound pressure level with FAST time constant as specified in IEC 61672-1 ¹
$L_{AF,max}$	Maximum time-weighted and A-weighted sound pressure level with FAST time constant within a stated time interval starting at t_1 and ending at t_2 , expressed in dB
$L_{AS,max}$	Maximum time-weighted and A-weighted sound pressure level with SLOW time constant within a stated time interval starting at t_1 and ending at t_2 , expressed in dB
L_E	Sound energy density level is the logarithmic ratio of the time-averaged sound energy per unit volume to the reference sound energy density $E_0 = 10^{-12} \text{ J/m}^3$.
$L_{ex,8h}$	L_{eq} (equivalent continuous sound level) corrected for the length of the working shift, in this case 8 hours
L_{day}	Equivalent continuous sound pressure level when the reference time interval is the day ¹
L_{den}	Day-evening-night-weighted sound pressure level as defined in section 3.6.4 of ISO 1996-1:2016 ¹
L_{dn}	Day-night-weighted sound pressure level as defined in section 3.6.4 of ISO 1996-1:2016 ¹
$L_{evening}$	Equivalent continuous sound pressure level when the reference time interval is the evening ¹

¹ Source: ISO (2016).

L_{night}	Equivalent continuous sound pressure level when the reference time interval is the night ¹
$L_{\text{peak,C}}$	Level of peak sound pressure with C-weighting, within a specified time interval
$L_{\text{peak,lin}}$	Level of peak sound pressure with linear frequency weighting, within a specified time interval
Sound pressure level	the logarithm of the ratio of a given sound pressure to the reference sound pressure in dB is 20 times the logarithm to the base ten of the ratio.
SLOW	Slow response has a time constant of 10 000 milliseconds on a sound level meter

Executive summary

Environmental noise is an important public health issue, featuring among the top environmental risks to health. It has negative impacts on human health and well-being and is a growing concern among both the general public and policy-makers in Europe.

At the Fifth Ministerial Conference on Environment and Health in Parma, Italy, in 2010, WHO was requested by the Member States in the European Region to produce noise guidelines that included not only transportation noise sources but also personal electronic devices, toys and wind turbines, which had not yet been considered in existing guidelines. Furthermore, European Union Directive 2002/49/EC relating to the assessment and management of environmental noise (END) and related technical guidance from the European Environment Agency both elaborated on the issue of environmental noise and the importance of up-to-date noise guidelines.

The WHO Regional Office for Europe has therefore developed environmental noise guidelines for the European Region, proposing an updated set of public health recommendations on exposure to environmental noise.

Objectives

The main purpose of these guidelines is to provide recommendations for protecting human health from exposure to environmental noise originating from various sources: transportation (road traffic, railway and aircraft) noise, wind turbine noise and leisure noise. Leisure noise in this context refers to all noise sources that people are exposed to due to leisure activities, such as attending nightclubs, pubs, fitness classes, live sporting events, concerts or live music venues and listening to loud music through personal listening devices. The guidelines focus on the WHO European Region and provide policy guidance to Member States that is compatible with the noise indicators used in the European Union's END.

The following two key questions identify the issues addressed by the guidelines.

- In the general population exposed to environmental noise, what is the exposure–response relationship between exposure to environmental noise (reported as various indicators) and the proportion of people with a validated measure of health outcome, when adjusted for confounders?
- In the general population exposed to environmental noise, are interventions effective in reducing exposure to and/or health outcomes from environmental noise?

In light of these questions, the guidelines set out to define recommended exposure levels for environmental noise in order to protect population health.

Methods used to develop the guidelines

The process of developing the WHO guidelines followed a rigorous methodology involving several groups with separate roles and responsibilities. Throughout the process, the Grading of

Recommendations Assessment, Development and Evaluation (GRADE) approach was followed. In particular, the different steps in the development of the guidelines included:

- formulation of the scope and key questions of the guidelines;
- review of the pertinent literature;
- selection of priority health outcome measures;
- a systematic review of the evidence;
- assessment of certainty of the bodies of evidence resulting from systematic reviews;
- identification of guideline exposure levels; and
- setting of the strength of recommendations.

Based on the defined scope and key questions, these guidelines reviewed the pertinent literature in order to incorporate significant research undertaken in the area of environmental noise and health since the community noise guidelines and night noise guidelines for Europe were issued (WHO, 1999; WHO Regional Office for Europe, 2009). In total, eight systematic reviews of evidence were conducted to assess the relationship between environmental noise and the following health outcomes: cardiovascular and metabolic effects; annoyance; effects on sleep; cognitive impairment; hearing impairment and tinnitus; adverse birth outcomes; and quality of life, mental health and well-being. A separate systematic review of evidence was conducted to assess the effectiveness of environmental noise interventions in reducing exposure and associated impacts on health.² Once identified and synthesized, the quality of the evidence of the systematic reviews was assessed by the Systematic Review Team. Subsequently, the Guideline Development Group (GDG) formulated recommendations, guided by the Systematic Review Team's assessment and informed by a number of additional contextual parameters. To facilitate the formulation of recommendations, the GDG first defined priority health outcomes and then selected the most relevant health outcome measures for the outcomes. Consecutively, a process was developed to identify the guideline exposure levels with the help of the exposure–response functions provided by the systematic reviews. To reflect the nature of the research (observational studies) underpinning the relationship between environmental noise and health, the GRADE procedures were adapted to the requirements of environmental exposure studies where needed.

Noise indicators

From a scientific point of view, the best noise indicator is the one that performs best in predicting the effect of interest. There are, however, a number of additional criteria that may influence the choice of indicator. For example, various indicators might be suitable for different health end-points. Some considerations of a more political nature can be found in the European Commission's Position paper on EU noise indicators (EC, 2000).

² All systematic reviews are publicly available online in the *International Journal of Environmental Research and Public Health*. A detailed list of links to the individual reviews is provided in section 2.3.2 and in Annex 2 of these guidelines.

The current guidelines are intended to be suitable for policy-making in the WHO European Region. They therefore focus on the most used noise indicators L_{den} and/or L_{night} (see the glossary of acoustic terms for further details). They can be constructed using their components (L_{day} , L_{evening} , L_{night} and the duration in hours of L_{night}), and are provided for exposure at the most exposed façade, outdoors. The L_{den} and L_{night} indicators are those generally reported by authorities and are widely used for exposure assessment in health effect studies.

Recommendations

Specific recommendations have been formulated for road traffic noise, railway noise, aircraft noise, wind turbine noise and leisure noise. Recommendations are rated as either strong or conditional.

Strength of recommendation

- A **strong** recommendation can be adopted as policy in most situations. The guideline is based on the confidence that the desirable effects of adherence to the recommendation outweigh the undesirable consequences. The quality of evidence for a net benefit – combined with information about the values, preferences and resources – inform this recommendation, which should be implemented in most circumstances.
- A **conditional** recommendation requires a policy-making process with substantial debate and involvement of various stakeholders. There is less certainty of its efficacy owing to lower quality of evidence of a net benefit, opposing values and preferences of individuals and populations affected or the high resource implications of the recommendation, meaning there may be circumstances or settings in which it will not apply.

Alongside specific recommendations, several guiding principles were developed to provide generic advice and support for the incorporation of recommendations into a policy framework. They apply to the implementation of all of the specific recommendations.

Guiding principles: reduce, promote, coordinate and involve

- Reduce exposure to noise, while conserving quiet areas.
- Promote interventions to reduce exposure to noise and improve health.
- Coordinate approaches to control noise sources and other environmental health risks.
- Inform and involve communities potentially affected by a change in noise exposure.

The recommendations, source by source, are as follows.



Road traffic noise

Recommendation	Strength
For average noise exposure, the GDG strongly recommends reducing noise levels produced by road traffic below 53 decibels (dB) L_{den} , as road traffic noise above this level is associated with adverse health effects.	Strong
For night noise exposure, the GDG strongly recommends reducing noise levels produced by road traffic during night time below 45 dB L_{night} , as night-time road traffic noise above this level is associated with adverse effects on sleep.	Strong
To reduce health effects, the GDG strongly recommends that policy-makers implement suitable measures to reduce noise exposure from road traffic in the population exposed to levels above the guideline values for average and night noise exposure. For specific interventions, the GDG recommends reducing noise both at the source and on the route between the source and the affected population by changes in infrastructure.	Strong



Railway noise

Recommendation	Strength
For average noise exposure, the GDG strongly recommends reducing noise levels produced by railway traffic below 54 dB L_{den} , as railway noise above this level is associated with adverse health effects.	Strong
For night noise exposure, the GDG strongly recommends reducing noise levels produced by railway traffic during night time below 44 dB L_{night} , as night-time railway noise above this level is associated with adverse effects on sleep.	Strong
To reduce health effects, the GDG strongly recommends that policy-makers implement suitable measures to reduce noise exposure from railways in the population exposed to levels above the guideline values for average and night noise exposure. There is, however, insufficient evidence to recommend one type of intervention over another.	Strong



Aircraft noise

Recommendation	Strength
For average noise exposure, the GDG strongly recommends reducing noise levels produced by aircraft below 45 dB L_{den} , as aircraft noise above this level is associated with adverse health effects.	Strong
For night noise exposure, the GDG strongly recommends reducing noise levels produced by aircraft during night time below 40 dB L_{night} , as night-time aircraft noise above this level is associated with adverse effects on sleep.	Strong
To reduce health effects, the GDG strongly recommends that policy-makers implement suitable measures to reduce noise exposure from aircraft in the population exposed to levels above the guideline values for average and night noise exposure. For specific interventions the GDG recommends implementing suitable changes in infrastructure.	Strong



Wind turbine noise

Recommendation	Strength
For average noise exposure, the GDG conditionally recommends reducing noise levels produced by wind turbines below 45 dB L_{den} , as wind turbine noise above this level is associated with adverse health effects.	Conditional
No recommendation is made for average night noise exposure L_{night} of wind turbines. The quality of evidence of night-time exposure to wind turbine noise is too low to allow a recommendation.	
To reduce health effects, the GDG conditionally recommends that policy-makers implement suitable measures to reduce noise exposure from wind turbines in the population exposed to levels above the guideline values for average noise exposure. No evidence is available, however, to facilitate the recommendation of one particular type of intervention over another.	Conditional



Leisure noise

Recommendation	Strength
For average noise exposure, the GDG conditionally recommends reducing the yearly average from all leisure noise sources combined to 70 dB $L_{Aeq,24h}$ as leisure noise above this level is associated with adverse health effects. The equal energy principle ³ can be used to derive exposure limits for other time averages, which might be more practical in regulatory processes.	Conditional
For single-event and impulse noise exposures, the GDG conditionally recommends following existing guidelines and legal regulations to limit the risk of increases in hearing impairment from leisure noise in both children and adults.	Conditional
Following a precautionary approach, to reduce possible health effects, the GDG strongly recommends that policy-makers take action to prevent exposure above the guideline values for average noise and single-event and impulse noise exposures. This is particularly relevant as a large number of people may be exposed to and at risk of hearing impairment through the use of personal listening devices. There is insufficient evidence, however, to recommend one type of intervention over another.	Strong

Target audience

The guidelines are published by the WHO Regional Office for Europe. In terms of their health implications, the recommended exposure levels can be considered applicable in other regions and suitable for a global audience, as a large body of the evidence underpinning the recommendations was derived not only from European noise effect studies but also from research in other parts of the world – mainly in America, Asia and Australia.

³ The equal energy principle states that the total effect of sound is proportional to the total amount of sound energy received by the ear, irrespective of the distribution of that energy in time (WHO, 1999).

1. Introduction

Environmental noise features among the top environmental risks to physical and mental health and well-being, with a substantial associated burden of disease in Europe (WHO Regional Office for Europe & JRC, 2011; Hänninen et al., 2014). It has negative impacts on human health and well-being and is a growing concern among both the general public and policy-makers in Europe.

WHO published community noise guidelines (CNG) and night noise guidelines (NNG) for Europe in 1999 and 2009, respectively (WHO, 1999; WHO Regional Office for Europe, 2009). Since then, significant new evidence has accumulated on the health effects of environmental noise.

The need for updated health-based guidelines originates in part from commitments made at the Fifth Ministerial Conference on Environment and Health in Parma, Italy, in 2010, where Member States asked WHO to produce appropriate noise guidelines that would include additional noise sources such as personal electronic devices, toys and wind turbines (WHO Regional Office for Europe, 2010). Furthermore, European Union (EU) Directive 2002/49/EC relating to the assessment and management of environmental noise (the END – EC, 2002a) and related technical guidance from the European Environment Agency (EEA) both elaborated on the issue of environmental noise and the importance of up-to-date noise guidelines (EEA, 2010).

The WHO Regional Office for Europe has therefore developed environmental noise guidelines for the European Region, proposing an updated set of public health recommendations on exposure to environmental noise. The main purpose of these guidelines is to provide recommendations for protecting human health from exposure to environmental noise originating from various sources: transportation (road traffic, railway and aircraft) noise, wind turbine noise and leisure noise. The guidelines focus on the WHO European Region and provide policy guidance to Member States that is compatible with the noise indicators used in the EU's END.

The following two key questions identify the issues addressed by the guidelines.

- In the general population exposed to environmental noise, what is the exposure–response relationship between exposure to environmental noise (reported as various indicators) and the proportion of people with a validated measure of health outcome, when adjusted for confounders?
- In the general population exposed to environmental noise, are interventions effective in reducing exposure to and/or health outcomes from environmental noise?

1.1 The public health burden from environmental noise

Exposure to noise can lead to auditory and nonauditory effects on health. Through direct injury to the auditory system, noise leads to auditory effects such as hearing loss and tinnitus. Noise is also a nonspecific stressor that has been shown to have an adverse effect on human health, especially following long-term exposure. These effects are the result of psychological and physiological distress, as well as a disturbance of the organism's homeostasis and increasing allostatic load (Basner et al., 2014). This is further outlined in the WHO narrative review of the biological mechanisms of nonauditory effects (Eriksson et al., 2018).

The evidence of the association between noise exposure and health effects is based on experimental work regarding biological plausibility and, in observational studies, consistency among study results, presence of an exposure–response relationship and the magnitude of the effect. Environmental noise risk assessment and risk management relies on established exposure–response relationships (Babisch, 2014).

In 2011 the WHO Regional Office for Europe and the European Commission (EC) Joint Research Centre (JRC) published a report on the burden of disease from environmental noise that quantified the healthy years of life lost in western European countries as a result of environmental noise (WHO Regional Office for Europe & JRC, 2011). The burden of disease is calculated, in a single measure of disability-adjusted life-years (DALYs), as the sum of the years of life lost from premature mortality and the years lived with disability for people living with the disease or health condition or its consequences in the general population (WHO, 2014a).

Sufficient information was deemed available to quantify the burden of disease from environmental noise for cardiovascular disease, cognitive impairment in children, sleep disturbance, tinnitus and annoyance. The report, based on a limited set of data, estimated that DALYs lost from environmental noise in western European countries are equivalent to 61 000 years for ischaemic heart disease (IHD), 45 000 years for cognitive impairment in children, 903 000 years for sleep disturbance, 22 000 years for tinnitus and 654 000 years for annoyance (WHO Regional Office for Europe & JRC, 2011). These results indicate that at least one million healthy years of life are lost every year from traffic-related environmental noise in western Europe. Sleep disturbance and annoyance, mostly related to road traffic noise, constitute the bulk of this burden. Available assessments place the burden of disease from environmental noise as the second highest after air pollution (WHO Regional Office for Europe & JRC, 2011; Hänninen et al., 2014; WHO 2014b). However, a lack of noise exposure data in the central and eastern parts of the WHO European Region means that it is not possible to assess the burden of disease from environmental noise for the whole Region.

1.2 The environmental noise policy context in the EU

The EU has been working to develop a harmonized noise policy for more than two decades. 1993 saw the start of the EC's Fifth Environment Action Programme, which stated that “no person should be exposed to noise levels which endanger health and quality of life” (EC, 1993). This was followed by a Green Paper on future noise policy (EC, 1996), which reinforced the importance of noise as one of the main environmental problems in Europe and proposed a new framework for noise policy development.

The Sixth Environment Action Programme had as one of its objectives: “to achieve a quality of environment where the levels of man-made contaminants do not give rise to significant impacts on, or risks to, human health” (EC, 2002b). This paved the way for the Commission to adopt and implement the END in 2002 (EC, 2002a). The main aim of the Directive is “to define a common approach intended to avoid, prevent or reduce on a prioritized basis the harmful effects, including annoyance, due to exposure to environmental noise”.

The END obliges the EC to adapt its Annexes I–III (I on noise indicators in addition to L_{den} ⁴ and L_{night} ⁵, II on noise assessment methods and III on methods for assessing harmful effects of noise) to technical and scientific progress. While work on revising Annex II was finalized in 2015 and common noise assessment methods were introduced (EC, 2015), revisions of Annex III to establish methods to assess the harmful effects of noise only started in 2015. Annex III would primarily define what exposure–response relationships should be used to assess the effect of noise on populations. EU Member States have already expressed the view that the recommendations from these environmental noise guidelines for the WHO European Region will guide the revision of Annex III. Beside this main directive, few other legislative documents cover different noise sources and other related issues in the EU (EEA, 2014: Annex I).

The Seventh Environment Action Programme, which guides European environment policy until 2020 (EC, 2014a), is committed to safeguarding the EU's citizens from environment-related risks to health by ensuring that by 2020 “noise pollution in the Union has significantly decreased, moving closer to WHO-recommended levels”. A particular requirement for achieving this is “implementing an updated EU noise policy aligned with the latest scientific knowledge, and measures to reduce noise at source, and including improvements in city design”.

In addition to the EU's END, several national governments also have legislation and/or limit values that apply at national and/or regional levels (WHO Regional Office for Europe, 2012). The EEA, through its European Topic Centre on Land Use and Spatial Information, gathers noise exposure data and maintains the Noise Observation and Information Service for Europe, based on strategic noise maps provided by Member States (EEA, 2018). A total of 33 EEA countries, in addition to six cooperating countries in south-eastern Europe, report information on noise exposure to the EEA, following the requirements of the END. The quality and availability of noise exposure assessment differs between EU and non-EU Member States where, even if noise legislation has been harmonized with the Directive, noise mapping and action plans are still at the planning stage (EEA, 2014; 2017a; WHO Regional Office for Europe, 2012).

1.2.1 Definition of indicators in the END

The END specifies a number of noise indicators to be applied by Member States in noise mapping and action planning. The most important are L_{den} and L_{night} .

The L_{den} indicator is an average sound pressure level over all days, evenings and nights in a year (EEA, 2010). This compound indicator was adopted by the EU in the END (EC, 2002a). The L_{den} in decibels (dB) is defined by a specific formula, where:

- L_{day} is the A-weighted long-term average sound level as defined in ISO 1996-1: 2016, determined over all the day periods of a year;
- L_{evening} is the A-weighted long-term average sound level as defined in ISO 1996-1: 2016, determined over all the evening periods of a year; and
- L_{night} is the A-weighted long-term average sound level as defined in ISO 1996-1: 2016, determined over all the night periods of a year (ISO, 2016).

⁴ Day-evening-night-weighted sound pressure level as defined in section 3.6.4 of ISO 1996-1:20161 (ISO, 2016).

⁵ Equivalent continuous sound pressure level when the reference time interval is the night.

The L_{night} , according to the definition in the END, is an equivalent outdoor sound pressure level, measured at the most exposed façade, associated with a particular type of noise source during night time (at least eight hours), calculated over a period of a year (WHO Regional Office for Europe, 2009).

Annex I of the END gives technical definitions for L_{den} and L_{night} , as well as supplementary noise indicators, which might be useful for monitoring special noise situations. For example, in the case of noisy but short-lived noise like shooting noise or noise emitted by trains, $L_{\text{A,max}}$ is often used. This is a measure of the maximum sound pressure reached during a defined measurement period. It is used to set noise limits and is sometimes considered in studies to determine certain health effects (such as awakening reactions).

1.3 Perceptions of environmental noise in the WHO European Region

1.3.1 Trends at the regional level

The general population greatly values the benefits of clean and quiet environments. In Europe, people perceive noise as an important issue that affects human health and well-being (EC, 2008; 2014b). In recent years, several Europe-wide surveys have examined the perception of noise as an issue among the population. Overall, these surveys ask about generic noise, referring to “neighbourhood noise” or “noise from the street”. This type of noise differs significantly in its definition from what is considered “environmental noise” in these guidelines. Nevertheless, in the absence of specific large surveys on perceptions of environmental noise as defined in these guidelines, the results provide insight into the public perception of this issue.

The European quality-of-life surveys, carried out every four years, are unique, pan-European surveys examining both the objective circumstances of lives of European citizens and how they feel about those circumstances and their lives in general. The last (fourth) survey was conducted in 2016–2017, involving nearly 37 000 citizens from all EU Member States and the five candidate countries (Albania, Montenegro, Serbia, the former Yugoslav Republic of Macedonia and Turkey). Respondents were asked whether they had major, moderate or no problems with noise in the immediate neighbourhood of their home. Almost one third (32%) reported problems with noise (ranging from 14% to 51% in individual countries), mainly in cities or city suburbs (49%) (Eurofound, 2017).

A 2010 survey of the then 27 countries in the EU, requested by the EC, showed that 80% of respondents ($n = 26\,602$) believed that noise affects their health, either to some or to a great extent (EC, 2010).

A Eurobarometer report on attitudes of European citizens towards the environment (EC, 2014b) compiled opinions on various environmental risks from almost 28 000 respondents in 28 EU countries. Results showed that for 15% of respondents, noise pollution is one of the top five environmental issues they are worried about. Furthermore, 17% of respondents said that they lack information about noise pollution.

1.3.2 Trends at the national level

Data on perception of specific sources of environmental noise as a problem are not available for the entire WHO European Region. Nevertheless, some countries – including France, Germany, the Netherlands, Slovakia and the United Kingdom – conduct national surveys on noise annoyance, either regularly or on demand (Sobotova et al., 2006; Lambert & Philipps-Bertin, 2008; van Poll et al., 2011; Centraal Bureau voor de Statistiek, 2012; Notley et al., 2014; Umweltbundesamt, 2017).

According to these large-scale surveys, road traffic noise is the most important source of annoyance, generally followed closely by neighbour noise. Aircraft noise can also be a substantial source of annoyance. Railway noise and industrial noise are enumerated less frequently. Only limited data are available on the population's perception of newer sources of noise, such as wind turbines.

While perception surveys do not provide information on actual quantitative relationships between noise exposure and health outcomes, it is important to note that the results of such surveys represent people's preferences and values regarding environmental noise. Despite limitations and an incomplete picture, the available data on perception of environmental noise as a public health problem show concern in Europe. People are not always aware of the health impacts of noise, especially of those related to long-term noise exposure at lower levels. Greater awareness of the issue may further increase positive values and preferences.

1.4 Target audience

The environmental noise guidelines for the European Region serve as a reference for an audience made up of different groups, with varied areas of expertise including decision-making, research and advocacy. More specifically, this covers:

- various technical experts and decision-makers at the local, national or international levels, with responsibility for developing and implementing regulations and standards for noise control, urban planning and housing, and other relevant environment and health domains;
- health impact assessment and environmental impact assessment practitioners and researchers;
- national and local authorities responsible for developing and implementing relevant measures and for risk communication;
- nongovernmental organizations and other advocacy groups involved in risk communication and general awareness-raising.

These guidelines are published by the WHO Regional Office for Europe. In terms of their health implications, the recommended exposure levels can be considered applicable in other regions and suitable for a global audience, as a large body of the evidence underpinning the recommendations was derived not only from European noise effect studies but also from research in other parts of the world – mainly in America, Asia and Australia.

2. Development of the guidelines

2.1 Overview

The process of developing WHO guidelines follows a rigorous methodology and involves several groups with well defined roles and responsibilities (WHO, 2014c). These include: formulation of the scope and key questions of the guidelines; review of the pertinent literature; selection of priority health outcome measures; a systematic review of the evidence; an assessment of certainty of the bodies of evidence resulting from systematic reviews; identification of guideline exposure levels; and setting of the strength of recommendations. Throughout the process, the Grading of Recommendations Assessment, Development and Evaluation (GRADE) approach was followed (Morgan et al., 2016).

The development of environmental noise guidelines started in 2013. Following WHO's procedures, the WHO Regional Office for Europe, through its European Centre for Environment and Health in Bonn, Germany, obtained planning approval and established a Steering Group and a Guideline Development Group (GDG). The former was primarily involved in initiating, structuring and executing the guideline development process; the latter was composed of leading experts and end-users, responsible for the process of scoping the guidelines and developing the evidence-based recommendations. During the initiation meeting in October 2013 in Bonn, the GDG members defined the scope of the guidelines, decided on the key questions to be addressed, prioritized health outcomes and set a timeline for completion of the work. Furthermore, authors were appointed for background papers, systematic reviews and different guideline background chapters.

In October 2014 a main evidence review meeting was held between the GDG and the Systematic Review Team in Bern, Switzerland, to discuss the evidence review drafts. In October 2014 and May 2015 the GDG met in Bern and Bonn, respectively, to refine the scope and draft recommendations. The revision and finalization of the systematic reviews of evidence was completed in early 2017. Through a series of remote meetings and teleconferences, the GDG discussed and addressed the remaining outstanding issues and feedback from the peer review of the draft guidelines, and decided on the final formulation of the recommendations. The following sections describe the steps of the guideline development process in detail.

2.2 Scope of the guidelines

Defining the scope of the guidelines included the selection of noise sources to be considered, as well as situations in which people are exposed, and noise indicators used for the formulation of recommendations. These guidelines separately consider outdoor exposure to environmental noise from road traffic, railway traffic, aircraft, wind turbines as well as outdoor and indoor exposure during leisure activities (such as attending nightclubs, pubs, fitness classes, live sporting events, concerts or live music venues and listening to loud music through personal listening devices). The guidelines are source specific and not environment specific. They therefore cover all settings where people spend a significant portion of their time, such as residences, educational institutions, workplaces and public venues, although hospital noise is exempted from the list of public institutions owing to the unique characteristics of the population involved.

The GDG agreed not to develop specific recommendations for occupational and industrial noise. Industrial noise can affect both people working at an industrial site and those living in its vicinity. The guidelines do not consider workers' exposure to noise in industrial environments, as these are regulated by workplace standards and may, in some cases, require the wearing of protective equipment or application of other preventive and protective measures. Further, the guidelines do not explicitly consider industrial noise as an environmental noise source, affecting people living in the vicinities of industrial sites. This is mainly due to the large heterogeneity and specific features of industrial noise, and the fact that exposure to industrial noise has a very localized character in the urban population.

Likewise, the current guidelines do not provide specific recommendations for the prevention of health effects linked to neighbourhood noise. Neighbourhood noise may stem from various potential sources of noise (such as ventilation systems; church bells; animals; neighbours; commercial, recreational and occupational activities; or shooting/military). As the sources may be located in close proximity to where people live, they can cause considerable concern even at low levels (Omlin et al., 2011). Several of these sources can also produce low-frequency noise, and as such, require indoor measurements for proper exposure assessment. In general, little scientific research is available on exposure and health outcomes related to neighbourhood noise.

Moreover, the guidelines do not include recommendations about any kind of multiple exposures. In everyday life people are often exposed to noise from several sources at the same time. In Germany, for example, 44% of the population are annoyed by at least two and up to five sources of noise (Umweltbundesamt, 2015). For some health outcomes, such as obesity, new evidence indicates that combined exposure to noise from several means of transportation is particularly harmful (Pyko et al., 2015; 2017).

Research indicates that, alongside exposure to more than one source of noise, combined exposure to different factors – for example, noise and vibration or noise and air pollution – has gained increasing relevance in recent years (Sørensen et al., 2017). The EC estimates that the social cost of noise and air pollution is up to €1 trillion every year (EC, 2016a). WHO acknowledges the need to develop comprehensive models to quantify the effects of multiple exposures on human health. As the main body of evidence on environmental noise still focuses on source-specific impacts of noise on health outcomes and does not incorporate combined exposure effects of multiple noise sources or other pollutants, however, the current guidelines provide recommendations for each source of noise specifically. No attempt has been made to combine noise from multiple sources for any particular health outcome.

2.2.1 Key questions

The environmental noise guidelines for the WHO European Region seek to address two main questions, which define the issues addressed by the guideline recommendations.

- In the general population exposed to environmental noise, what is the exposure–response relationship between exposure to environmental noise (reported as various indicators) and the proportion of people with a validated measure of health outcome, when adjusted for confounders?
- In the general population exposed to environmental noise, are interventions effective in reducing exposure to and/or health outcomes from environmental noise?

2.2.2 Environmental noise indicators used in the guidelines

From a scientific point of view, the best noise indicator is the one that performs best in predicting the effect of interest. There are, however, a number of additional criteria that may influence the choice of indicator because, for example, various indicators might be suitable for different health end-points and some indicators are more practical to use or easier to calculate than others. Some of these considerations are of a more political nature, as mentioned in the EC's Position paper on EU noise indicators (EC, 2000).

The current guidelines are intended to be suitable for policy-making primarily in the WHO European Region. They are therefore based on the most frequently used average noise indicators in Europe: L_{den} and L_{night} . These are often reported by authorities and are used widely for exposure assessment in health effect studies and noise impact assessments in the Region. The L_{den} (also referred to as "DENL") indicator can be calculated as the A-weighted average sound pressure level, measured over a 24-hour period, with a 10 dB penalty added to the average level in the night (23:00–07:00 or 22:00–06:00), a 5 dB penalty added to the evening (19:00–23:00 or 18:00–22:00) and no penalty added to the daytime period (07:00–19:00 or 06:00–18:00). The penalties are introduced to indicate people's extra sensitivity to noise during the evening and night. The L_{night} indicator is the A-weighted average sound pressure level, measured over an eight-hour period during night time, usually between 23:00 and 07:00 (EC, 2002a).

In these guidelines, L_{den} and L_{night} refer to a measurement or calculation of noise exposure at the most exposed façade, outdoors, reflecting the long-term average exposure. Thus, L_{den} and L_{night} represent all the single noise events due to a specific noise source that occur over a longer period of time, such as during a year. Moreover, most health outcomes considered in these guidelines are expected to occur as a result of long-term exposure. It is generally accepted that the most relevant parts of the whole day or night, which especially account for the time when a person is at home, are correctly attributed when using average indicators like L_{den} or L_{night} .

The majority of studies that form the body of evidence for the recommendations in these guidelines – among them large-scale epidemiological studies and socioacoustic surveys on annoyance and self-reported sleep disturbance – refer to noise exposure measured outdoors, usually at the most exposed façade of dwellings. Virtually all noise exposure prediction models in use today estimate free-field exposure levels outdoors, and most noise abatement regulations refer to outdoor levels as well. These are the practical reasons why the GDG decided not to recommend any guideline values for noise indoors. Nevertheless, in certain cases it could be helpful to estimate indoor levels based on outdoor values. The differences between indoor and outdoor levels are usually estimated at around 10 dB for open, 15 dB for tilted or half-open and about 25 dB for closed windows. When considering more accurate estimation of indoor levels, using a range of different predictors, the relevant scientific literature can be consulted (Locher et al., 2018).

The GDG was aware of the fact that many countries outside the EU are not bound by the terms of the END (EC, 2002a) and/or use noise indicators other than L_{den} or L_{night} in their noise regulations. They still can make use of these guidelines, however, because energy-based average noise indicators are usually highly correlated and "rule of thumb" transformations from one indicator to another are possible with acceptable uncertainty, as long as the conversion accounts for the long-term average

of populations, rather than individual exposure situations. Empirically derived generic conversion terms between a wide range of different noise indicators (including L_{den} , L_{dn} , L_{day} , L_{night} and $L_{\text{Aeq,24h}}$; see the glossary of acoustic terms for further details), with their uncertainty estimates, were published recently (Brink et al., 2018). The GDG encourages the use of these conversions, should the need arise.

In many situations, average noise levels like the L_{den} or L_{night} indicators may not be the best to explain a particular noise effect. Single-event noise indicators – such as the maximum sound pressure level ($L_{\text{A,max}}$)⁶ and its frequency distribution – are warranted in specific situations, such as in the context of night-time railway or aircraft noise events that can clearly elicit awakenings and other physiological reactions that are mostly determined by $L_{\text{A,max}}$. Nevertheless, the assessment of the relationship between different types of single-event noise indicators and long-term health outcomes at the population level remains tentative. The guidelines therefore make no recommendations for single-event noise indicators.

Different noise sources – for example, road traffic noise and railway noise – can be characterized by different spectra, different noise level rise times of noise events, different temporal distributions of noise events and different frequency distributions of maximum levels. Because of the extensive differences in the characteristics of individual noise sources, these guidelines only consider source-specific exposure–response functions (ERFs) and, therefore, formulate only source-specific recommendations.

2.3 Evidence base

Based on the overall scope and key questions the current guidelines review the relevant literature in the area of environmental noise and health in order to incorporate significant research undertaken since the publication of previous guidelines. The process of evidence search and retrieval involved several steps. These include the identification, retrieval and synthesis of the evidence, followed by a systematic review and assessment (described in section 2.4).

2.3.1 Identification, retrieval and synthesis of evidence

As a first step, the GDG identified key health outcomes associated with environmental noise. Next, it rated the relevance of these health outcomes according to the following three categories:

- critical for assessing environmental noise issues
- important, but not critical for assessing environmental noise issues
- unimportant.

The GDG rated the relevance based on the seriousness and prevalence of the outcomes and the anticipated availability of evidence for an association with noise exposure. The following health outcomes were selected as either critical or important for developing recommendations on the health impacts of environmental noise.

⁶ $L_{\text{A,max}}$ is the maximum time-weighted and A-weighted sound pressure level within a stated time interval starting at t1 and ending at t2, expressed in dB.

Critical health outcome

Cardiovascular disease
 Annoyance⁷
 Effects on sleep
 Cognitive impairment
 Hearing impairment and tinnitus

Important health outcome

Adverse birth outcomes
 Quality of life, well-being and mental health
 Metabolic outcomes

The GDG noted that research into the relationship between noise exposure and its effects on humans brings into focus several questions concerning the definition of health and the boundary between normal social reaction to noise and noise-induced ill health. As stated in WHO's Constitution: "Health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity" (WHO, 1946). Accordingly, documenting physical health does not present a complete picture of general health; and being undisturbed by noise in all activities, including sleep, constitutes an asset worthy of protection. Therefore, in accordance with the above definition, the GDG regarded (long-term) annoyance and impaired well-being, as well as self-reported sleep disturbance due to noise, as health outcomes.

Regarding sleep disturbance, the health outcome measures considered in these guidelines largely disregard "objective" indicators of sleep disturbance, such as the probability of awakening reactions or other polysomnography parameters. The main reason for this is the nature of the body of evidence on acute, objectively measured effects of noise during sleep. Studies of physiological effects of sleep and especially polysomnographic investigations are complex and resource-demanding; they therefore include only a small number of participants, who are often healthy young volunteers not representative of the general population. For these reasons, the majority of such studies do not meet the requirements for inclusion in the GRADE framework and full-scale meta-analysis, including adjustment for confounders. Furthermore, it is currently unclear how acute physiological reactions that affect the microstructure of sleep but are less well correlated with global sleep parameters, such as total sleep time, are related to long-term health impediments, especially considering the large interindividual differences in susceptibility to noise (Basner et al., 2011).

As sleeping satisfies a basic need and the absence of undisturbed sleep can have serious effects on human health (WHO Regional Office for Europe, 2009), the GDG set self-reported sleep disturbance, in line with the WHO definition of health, as a primary health outcome. Even though self-reported sleep disturbance might differ considerably from objectively measured parameters of sleep physiology, it constitutes a valid indicator in its own right, as it reflects the effects on sleep perceived by an individual over a longer period of time (WHO Regional Office for Europe & JRC, 2011). The importance of considering both annoyance and self-reported sleep disturbance as health outcomes is further supported by evidence indicating that they may be part of the causal pathway of noise-induced cardiovascular and metabolic diseases. This is further elaborated in the narrative review on biological mechanisms (Eriksson et al., 2018).

⁷ Noise annoyance is defined as a feeling of displeasure, nuisance, disturbance or irritation caused by a specific sound (Ouis, 2001). In the current guidelines, "annoyance" refers to long-term noise annoyance.

The second step in the evidence retrieval process constituted formulation of the key questions for the critical and important health outcomes and identification of the areas of evidence to be reviewed, following the PICOS/PECCOS approach defined in the WHO handbook for guideline development (WHO, 2014c). PICOS/PECCOS is an evidence-based technique that frames health care-related questions to facilitate the search for suitable studies that can provide answers to the questions at hand (Huang et al., 2006). The PICOS approach divides intervention questions into five elements: population, intervention, comparator, outcome and study design. In exposure studies, PICOS becomes PECCOS, which stands for population, exposure, comparator, confounder, outcome and study design. The specification of the elements of PICOS/PECCOS serves to construct the body of evidence that underpins each recommendation. Due to the complex nature of environmental noise, several distinct areas of evidence were defined to address each of the scoping questions comprehensively.

For each of the critical and important health outcomes a systematic review was conducted (see also section 2.3.2). Health outcomes regarded as important were given less weight in the decision-making process than critical ones. Inclusion and exclusion criteria to be regarded in the systematic evidence reviews were defined in accordance with the PICOS/PECCOS framework for the evaluation of evidence (see Table 1). All evidence that met the inclusion criteria was included in the systematic reviewing process. A detailed description of the types of measure for each of the health outcomes under consideration is provided in the protocol for conducting the systematic reviews (Héroux & Verbeek, 2018a). See Annex 2 for details of all background documents and systematic reviews used in preparation of these guidelines.

Table 1. Inclusion and exclusion criteria for evidence reviews of health effects of environmental noise

Category	Inclusion criteria	Exclusion criteria
Populations	- Members of the general population - Specific segments of the population particularly at risk (children or vulnerable groups) - People exposed to noise in occupational settings (if relevant with combined exposure to environmental noise)	Does not meet inclusion criteria
Exposure	- Noise exposure levels, either measured or calculated and expressed in dB values - Representative of the individual exposure of study participants (for most observational studies the dwelling location or home) - Calculated levels for transportation noise (road, rail, air) based on traffic data reflecting the use of roads, railway lines and in- and outbound flight routes at airports	- Does not meet inclusion criteria; in particular: - studies using hearing loss or hearing impairment as a proxy for (previous) noise exposure - surveys assessing noise exposure or number of listening hours based on subjective ratings given by subjects in a questionnaire
Confounders	No inclusion criteria applied since the relationship between exposure to noise and a health outcome can be confounded by other risk factors; however, possible confounders taken into account were assessed for every study	No exclusion criteria applied; however, possible confounders taken into account were assessed for every study



Table 1. contd.

Category	Inclusion criteria	Exclusion criteria
Outcomes	• Adverse birth outcomes • Annoyance • Cardiovascular disease • Cognitive impairment • Effects on sleep • Hearing impairment and tinnitus • Metabolic outcomes • Quality of life, mental health and well-being	• Does not meet inclusion criteria
Study types	• Cohort studies • Case-control studies • Cross-sectional studies • Ecological studies (only for cardiovascular disease)	• Does not meet inclusion criteria

Alongside the systematic reviews of the critical and important health outcomes, the GDG decided to review the evidence on health effects from noise mitigation measures and interventions to reduce noise levels in order to inform and complement the recommendations.

Interventions on environmental noise were defined according to five broad categories based on the available intervention literature and the experience of decades of environmental noise management (see Table 2 and Brown & van Kamp, 2017).

Table 2. Types of noise intervention

Intervention type	Intervention category	Intervention subcategory
A	Source intervention	• change in emission levels of sources • time restrictions on source operations
B	Path intervention	• change in the path between source and receiver • path control through insulation of receiver/receiver's dwelling
C	New/closed infrastructure	• opening of a new infrastructure noise source • closure of an existing one • planning controls between (new) receivers and sources
D	Other physical intervention	• change in other physical dimensions of dwelling/neighbourhood
E	Behaviour change intervention	• change in individual behaviour to reduce exposure • avoidance or duration of exposure • community education, communication

The GDG recognized that nonacoustic factors are an important possible confounder in both ERFs between noise levels and critical health effects and the effects of acoustic interventions on health outcomes. Whereas the inclusion criteria for confounders were not specified in PECCOS for the systematic reviews of evidence, they were considered at the stage of assessing the quality of

evidence, using the GRADE approach. Depending on the health effect under investigation, possible nonacoustic factors may include:

- gender
- age
- education
- subjective noise sensitivity
- extroversion/introversion
- general stress score
- co-morbidity
- length of residence
- duration of stay at dwelling in the day
- window orientation of a bedroom or living room towards the street
- personal evaluation of the source
- attitudes towards the noise source
- coping capacity with respect to noise
- perception of malfeasance by the authorities responsible
- body mass index
- smoking habits.

In noise annoyance studies nonacoustic factors may explain up to 33% of the variance (Guski, 1999). The higher the quality of evidence, the lower confounding effects of nonacoustic factors may be expected. Nevertheless, as with measurement errors, confounding cannot be avoided.

Based on the retrieval and evaluation of the pertinent literature, the GDG decided to address the association of environmental noise from different sources and health outcomes separately and individually for each source of noise, and for critical and important health outcomes.

In addition to the systematic reviews of the health effects of environmental noise, a narrative review of biological mechanisms of nonauditory effects was conducted (Eriksson et al., 2018). This covers literature related to pathways for nonauditory effects and provides supporting evidence on the association between environmental noise and health outcomes in humans, especially related to cardiovascular and metabolic diseases.

2.3.2 Systematic reviewing process

After the retrieval of the evidence based on the PICOS/PECCOS approach, systematic reviews were conducted for all critical and important health outcomes. To meet the demands of the diverse and broad nature of the evidence, it was agreed that systematic reviews could vary in type. For some areas of evidence, a novel and fully fledged systematic reviewing process was needed to summarize the existing evidence; for others, the reviewing process could build upon existing (and mostly published) systematic reviews and summaries of evidence. Thus, the process consisted of two phases.

First, a comprehensive search was conducted for available systematic reviews and meta-analyses on environmental noise effects published after 2000. Each of the reviews was assessed for both relevance and quality. To be included in the evidence review process, studies from these reviews were required to meet a high quality standard, judged according to high scores of the AMSTAR checklist.⁸ In cases where quality criteria were met but the review was older than two years (published before 2012), the search of the systematic review was updated to include new papers. If no good quality systematic reviews were available, a new search for original papers was conducted. The Systematic Review Team decided how the results would affect the search strategy for individual studies as part of the second phase. This was based on the assessment of the quality of the systematic reviews and on the coherence between the main research questions of the systematic reviews and the scope of the work of the guidelines.

In the second phase a search for individual papers was conducted, with the search strategy adapted according to the outcome of the first phase. As availability of systematic reviews and meta-analyses differed for the various health outcomes considered in the guidelines, this process varied for each evidence review. The search included cohort studies, case-control studies and cross-sectional studies of people exposed to environmental noise. Where relevant – for example, for the health outcome cardiovascular disease – the search also included ecological studies.

Due to the individualized retrieval of evidence for each of the systematic reviews, the time frames of the literature included varied. An indication of the temporal coverage of the studies included in different systematic review is provided in the relevant tables in Chapter 4.

A detailed description of the methodology used to conduct the systematic evidence reviews, including individual protocols for the reviews of health effects resulting from environmental noise and from noise interventions, is available (Héroux & Verbeek, 2018b). Furthermore, all systematic reviews conducted in the guideline development process are publicly available in the open-access journal *International Journal of Environmental Research and Public Health*:

- systematic review of transport noise interventions and their impacts on health (Brown & van Kamp, 2017);
- systematic review on environmental noise and adverse birth outcomes (Nieuwenhuijsen et al, 2017);
- systematic review on environmental noise and annoyance (Guski et al., 2017);
- systematic review on environmental noise and cardiovascular and metabolic effects (van Kempen et al., 2018);
- systematic review on environmental noise and cognition (Clark & Paunovic, 2018);
- systematic review on environmental noise and effects on sleep (Basner & McGuire, 2018);
- systematic review on environmental noise and permanent hearing loss and tinnitus (Śliwińska-Kowalska & Zaborowski, 2017);
- systematic review on mental health and well-being (Clark & Paunovic, in press).

⁸ AMSTAR is an instrument used to assess quality of evidence; it stands for “A Measurement Tool to Assess systematic Reviews” (Shea et al., 2007).

2.4 From evidence to recommendations

Once the evidence had been identified and synthesized, the Systematic Review Team assessed its quality. Subsequently, the GDG formulated recommendations, guided by this assessment and consideration of a number of other factors recognized as important. To facilitate the formulation of recommendations, it first prioritized the health outcome measures of the critical and important outcomes. A process was developed to identify the guideline exposure levels from each of the ERFs provided by the systematic reviews of evidence.

The following sections describe the assessment of the overall quality of the evidence based on the GRADE approach, selection of priority health outcome measurements, identification of guideline exposure levels and setting the strength of recommendations.

2.4.1 Assessment of overall quality of a body of evidence: the GRADE approach

As set out in the WHO handbook for guideline development (WHO, 2014c), the main framework for producing evidence-informed recommendations is the GRADE approach (Guyatt et al., 2008). This is used to assess the quality of a body of evidence synthesized in a systematic review. The assessment facilitates judgements about the certainty of effect estimates, which increases with the quality of the body of evidence. The quality can be rated high, moderate, low or very low (see Box 1).

Box 1 GRADE interpretations of quality of evidence

- **High quality:** further research is very unlikely to change the certainty of the effect estimate
- **Moderate quality:** further research is likely to have an important impact on the certainty of the effect estimate and may change the estimate
- **Low quality:** further research is very likely to have an important impact on the certainty of the effect estimate and is likely to change the estimate
- **Very low quality:** any effect estimate is uncertain

The original GRADE approach was developed specifically to rate the body of evidence resulting from a review of intervention studies. The initial quality level is set by study design: randomized control trials (RCTs) are considered high quality, whereas observational (nonrandomized) study designs are low quality. Then five factors are considered for downgrading the quality of the body of evidence resulting from RCTs or observational studies, and three factors are considered for upgrading the body of evidence resulting from observational studies alone.

The following five factors are used for downgrading the quality of evidence by one or two levels:

- study limitations or risk of bias in all studies that make up the body of evidence
- inconsistency of results between studies
- indirectness of evidence in the studies
- imprecision of the pooled effect estimate
- publication bias detected in a body of evidence.

The following three factors are used for upgrading the quality of evidence:

- high magnitude of the pooled effect
- direction of residual confounding and biases opposes an effect (i.e. when all plausible confounders are anticipated to reduce the estimated effect and there is still a significant effect)
- exposure–response gradient.

The GRADE approach was originally developed for application in the field of clinical medicine, where the majority of studies are randomized trials. However, to assess health effects resulting from an exposure such as environmental noise, randomized controlled trials are not applicable, as it would be unethical to expose participants deliberately to possibly harmful risk factors. The limitations of the application of GRADE to environmental health have been recognized and discussed in the literature (Morgan et al., 2016). Other types of study design dominate the evidence base in the domain of environmental noise research, so it was necessary to adapt the original GRADE approach to the subject of the current guidelines, as follows.

Instead of using the RCT study design as the starting-point for the quality rating, the study design most applicable and available for the field of research at hand was used. Thus, for evidence on the association between noise exposure and clinical health outcome measures, the rating of an evidence base consisting of cohort and case-control studies⁹ was initially rated high quality. Cross-sectional studies and ecological studies were rated low quality and very low quality, respectively. This initial point of departure was only adapted for the evidence of the association between noise exposure and annoyance and sleep disturbance. Here, cross-sectional studies were rated high quality because annoyance and sleep disturbance are regarded as an immediate effect of exposure to environmental noise. Finally, in accordance with the original GRADE approach, the starting-point for evidence on the effect of interventions was rated low quality for observational studies. After determining the point of departure, the evidence base was rated down or up whenever one or more of the criteria for downgrading or upgrading (described above) were met. Each of the systematic reviews commissioned for these guidelines includes a detailed report on the assessment of the quality of the evidence.

A detailed discussion of the adaptations of GRADE is provided in the separate methodology publication (Héroux & Verbeek, 2018b).

2.4.2 Selection of priority health outcomes

In line with the WHO handbook for guideline development (WHO, 2014c), the GDG selected the key health outcomes associated with environmental noise at the beginning of the evidence retrieval process, and the systematic reviews were commissioned accordingly. The selection of health outcomes was based on the available evidence for the association between environmental noise and the specific outcome, as well as public concern about the health outcome resulting from noise exposure. The following health outcomes were rated critical: cardiovascular disease, annoyance,

⁹ In the context of the current guidelines, “cohort studies” refer to longitudinal studies in which the occurrence of the outcome of interest in an exposed group is compared to the occurrence of that outcome in a reference group with no or lower exposure over time.

effects on sleep, cognitive impairment and hearing impairment and tinnitus. Adverse birth outcomes, quality of life, well-being and mental health, and metabolic outcomes were rated important (see also section 2.3.1).

Since all these health outcomes can be measured in various ways, the GDG evaluated each individually and prioritized different outcome measures for each in terms of their representativeness and validity. These measures were used to derive the guideline exposure levels; their prioritization was based on the impact of the disease and the disability weights (DWs) associated with the health outcome measure.¹⁰

The critical health outcomes, priority outcome measures identified and justifications for their selection are listed in Table 3.

Table 3. Critical health outcomes, outcome measures identified and justifications for selection

Critical health outcome	Critical health outcome measures (priority measures marked in bold)	Justification for selection
Cardiovascular disease (L_{den})	Self-reported or measured prevalence, incidence , hospital admission or mortality due to: • ischaemic heart disease (IHD) (including angina pectoris and/or myocardial infarction) • hypertension • stroke	Except for self-reports, these are objective measures of the outcome, affect a large proportion of the population, have important health consequences and can lead to more severe diseases and/or mortality. DW for IHD: 0.405. DW for hypertension: 0.117.
Effects on sleep (L_{night})	• percentage of the population highly sleep-disturbed (%HSD), self-reported, assessed with a standardized scale • polysomnography measured outcomes (probability of additional awakenings) • cardiac and blood pressure outcome measures during sleep • motility measured sleep outcomes in adults • sleep disturbance in children	This is the most meaningful, policy-relevant measure of this health outcome. Self-reported sleep disturbances are a very common problem in the general population: they affect quality of life directly and may also lead to subsequent health impediments. Effects on sleep may be in the causal pathway to cardiovascular disease. This measure is not a proxy for physiological sleep quality parameters but is an important outcome in its own right. DW for %HSD: 0.07.
Annoyance (L_{den})	• percentage of the population highly annoyed (%HA), assessed with standardized scale • percentage annoyed, preferably assessed with standardized scale	This is the most objective measure of this health outcome. Large proportions of the population are affected by noise annoyance, even at relatively low exposure levels. Annoyance may be in the causal pathway to cardiovascular disease. DW for %HA: 0.02.



¹⁰ DWs are ratings that vary between 0 and 1, in which 0 indicates no disability and 1 indicates the maximum amount of disability. The rates are derived from large population surveys in which people are asked to rank a specific disease for its impact on several abilities. The DWs have been proven useful in calculating the burden of disease.

Table 3. contd.

Critical health outcome	Critical health outcome measures (priority measures marked in bold)	Justification for selection
Cognitive impairment (L_{den})	• reading and oral comprehension, assessed with tests • impairment assessed with standardized tests • short and long-term memory deficit • attention deficit • executive function deficit (working memory capacity)	This outcome measure is the most meaningful: it can affect vulnerable individuals (children) and have a significant impact later in life. DW for impaired reading and oral comprehension: 0.006.
Hearing impairment and tinnitus (L_{Aeq}^{11} and $L_{AF,max}^{12}$)	• permanent hearing impairment, measured by audiometry • permanent tinnitus	This outcome measure can affect vulnerable individuals (children) and have a significant impact later in life. It is the most objective measure for which there is an ISO standard (ISO, 2013), specifying how to estimate noise-induced hearing loss. DW for mild severity level (threshold at 25 dB) for childhood onset: 0.0150.

Table 4 provides a list of the important health outcomes along with the corresponding health outcome measures included in the systematic reviews. There was no prioritization of health outcome measures leading to justification of selection, since important health outcomes had less impact on the development of recommendations.

Table 4. Important health outcomes and health outcome measures reviewed

Important health outcome	Health outcome measures reviewed
Adverse birth outcomes (L_{den})	• pre-term delivery • low birth weight • congenital anomalies
Quality of life, well-being and mental health (L_{den})	• self-reported health and quality of life • medication intake for depression and anxiety • self-reported depression, anxiety and psychological distress • interviewer-assessed depressive and anxiety disorders • emotional and conduct disorders in children • children's hyperactivity • other mental health outcomes
Metabolic outcomes (L_{den})	prevalence, incidence, hospital admission or mortality due to: • type 2 diabetes • obesity

¹¹ L_{Aeq} is an A-weighted, equivalent continuous sound pressure level during a stated time interval starting at t1 and ending at t2, expressed in dB, of a noise at a given point in space.

¹² $L_{AF,max}$ is the maximum time-weighted and A-weighted sound pressure level with FAST time constant within a stated time interval starting at t1 and ending at t2, expressed in dB.

2.4.3 Identification of guideline exposure levels for each noise source

The GDG agreed to set guideline exposure levels based on the definition: “noise exposure levels above which the GDG is confident that there is an increased risk of adverse health effects”. The identification of guideline values for each of the specific noise sources involved five distinct steps:

1. assessment of the validity of ERFs resulting from the systematic reviews of the effects of noise on each of the critical and important health outcomes;
2. assessment of the lowest noise level measured in the studies included in each of the corresponding systematic reviews;
3. assessment of the smallest risk or relative risk (RR) increase for each of the adverse health outcomes considered relevant;
4. determination of the guideline exposure level based on the ERF, starting from the lowest level measured (see step 2) and associated with the smallest relevant risk increase for adverse health outcomes (see step 3);
5. comparison of the guideline exposure levels calculated for each of the critical health outcomes of one source (for example, incidence of IHD, incidence of hypertension, %HA, permanent hearing impairment and reading and oral comprehension for road traffic noise): selection of the guideline exposure level for each noise source was based on the priority health outcome measure with the lowest exposure level for that source.

To define an “increased risk” to set the guideline exposure level, the GDG made a judgement about the smallest risk or RR of the adverse health effect it considered relevant for each of the priority health outcome measures. It is important to note that the relevant risk increases are benchmark values. The GDG agreed to set them in accordance with the guiding principles it had developed, to provide guideline values that illustrate an increased risk of adverse health effects. It used expert judgements for the determination of the benchmark values; these are elaborated further in section 2.4.3.2.

The guideline exposure levels presented are therefore not meant to identify effect thresholds (the lowest observed adverse effect levels for different health outcomes). This is a difference in approach from prior WHO guidelines, like the night noise guidelines for Europe (WHO Regional Office for Europe, 2009), which explicitly aimed to define levels indicating no adverse health effects. The approach to making choices about relevant risk increases is outlined below and summarized in Table 5.

For IHD and hypertension, RR increases were considered; for annoyance and sleep disturbance, absolute risks of %HA and %HSD were considered; and for reading and oral comprehension an average delay of reading age was defined. For the cardiovascular outcomes, incidence measures were prioritized, although much of the epidemiological evidence was based on prevalence data – particularly for hypertension – where almost no longitudinal studies were available. Prevalence data are generally derived from cross-sectional studies, where the temporal aspects are difficult to determine.

Table 5. Priority health outcomes and relevant risk increases for setting guideline levels

Priority health outcome measure (associated DW)	Relevant risk increase considered for setting of guideline level
Incidence of IHD (DW: 0.405)	5% RR increase
Incidence of hypertension (DW: 0.117)	10% RR increase
%HA (DW: 0.02)	10% absolute risk
%HSD (DW: 0.07)	3% absolute risk
Permanent hearing impairment (DW: 0.0150)	No risk increase due to environmental noise
Reading and oral comprehension (DW: 0.006)	One-month delay in terms of reading age

The DWs used to rank the priority critical health outcomes measures were retrieved from the relevant literature. For cardiovascular disease as a group and for hypertension, the burden of disease from environmental noise values (WHO Regional Office for Europe & JRC, 2011) were not considered applicable by the GDG for these guidelines. Thus, for cardiovascular disease, the DW value (DW: 0.405) specifically applied to acute myocardial infarction in the publication outlining the data sources, methods and results of the global burden of disease in 2002 (Mathers et al., 2003) was retained. Since hypertension is mainly viewed as an important risk factor and not as a health outcome, no general DW has been developed. The only other available DW value available is the DW of 0.117 for hypertensive episodes in pregnancy (Mathers et al., 1999). In the absence of any general DW, the GDG agreed on a conservative approach and decided to use this value.

The DWs for high sleep disturbance (DW: 0.07), high annoyance (DW: 0.02) and impaired reading and oral comprehension (DW: 0.006) were developed in the context of calculating the burden of disease from environmental noise (WHO Regional Office for Europe & JRC, 2011). The DW for hearing impairment was not included in that publication, but it was available from the technical paper on the burden of disease from environmental noise (WHO, 2013); the DW for permanent hearing impairment ranged from 0.0031 to 0.3342, depending on severity level. Environmental noise (leisure noise) contributes to the cumulative total noise exposure throughout the life-course, which may lead to permanent hearing impairment and cause more severe disability in the later years of life. As a result, the GDG selected a DW of 0.0150 for moderate severity level (“has difficulty following a conversation in a noisy environment, but no other hearing problems”). For cognitive impairment, the DW was derived from the estimates of the burden of disease from environmental noise (WHO Regional Office for Europe & JRC, 2011). This was at a very conservative value (DW: 0.006) for noise-related impairment of children’s cognition, equivalent to a DW for contemporaneous cognitive deficit in the context of a range of cognitive impairments in children ranging from 0.468 for Japanese encephalitis to 0.024 for iron deficiency anaemia (Lopez et al., 2006).

2.4.3.1 Development of ERFs

The systematic reviews of evidence provided either an ERF or other noise exposure value/metric that could be related to a risk increase of the health outcome measure. These ERFs were used to develop guideline exposure levels; however, only those functions where noise exposure demonstrated a statistically significant effect were used.

To obtain the starting level of the ERFs derived in the systematic reviews, a weighted average of the lowest exposure values measured in the individual studies included in the meta-analyses was

calculated. The weighting used the inverse of the variance of the effect estimate of the study. Thus, the lowest exposure value of studies with a small variance (usually with the largest sample size) contributed the most to the assumed onset of the ERF.

2.4.3.2 Relevant risk increase of adverse health effects

The following sections describe in detail the rationale for the selection of the relevant relative risk (RR) increase percentage for each of the priority health outcome measures considered.

Cardiovascular disease: IHD and hypertension

High-quality epidemiological evidence described in the systematic review on cardiovascular and metabolic effects of environmental noise indicates that exposure to road traffic noise increases the risk of IHD (van Kempen et al., 2018). The GDG was confident that health risks result from exposure at an RR increase in the order of 5–10% in the incidence of IHD. This is similar to the reasoning in the WHO air quality guidelines for fine particulate matter (PM_{2.5}) (WHO, 2006). To determine a relevant risk increase for IHD, the GDG took as a starting-point the RR increase of 5% measured in epidemiological studies of environmental noise or air pollution. Taking into account the incidence of IHD and the seriousness of the disease, it considered lowering the RR increase for IHD to 1%, as a 5% RR increase might imply a comparatively high absolute risk from a population perspective. To decide on the final benchmark value for IHD, several aspects were considered: the number of people in a population affected by IHD; whether health risks caused by noise would make up a large part of the incidence of the disease; other examples of health risks of similar magnitude leading to preventive action. For IHD, in an average EU country with 20 million inhabitants, an RR increase of 5% for IHD would lead to several thousand extra cases attributable to noise yearly. This corresponds to a proportion of cases of IHD attributable to noise exposure of less than 10%, which is still relatively small. After extensive discussion at the very end of the guideline development process, the GDG decided to adhere to 5% as the relevant risk increase.

Hypertension is a common condition and is an important risk indicator for IHD and other cardiovascular diseases. Thus, the hypertension risk increase can be transformed into a risk increase for cardiovascular disease. To derive a relevant risk increase, the GDG focused on the incidence of hypertension, owing to the nature and quality of epidemiological evidence. Since hypertension is less serious than IHD, and not all people with hypertension will progress to cardiovascular disease, the relevant risk increase in the incidence of hypertension needed to be higher than that for IHD. Therefore, the GDG agreed on an RR increase of 10% for hypertension.

Self-reported sleep disturbance and annoyance

The GDG initially considered 5%HSD and 10%HA due to noise as relevant absolute risks, not to be exceeded at the guideline level. After discussion, however, members agreed that these absolute risks were too large, since a considerable proportion of the population would still be affected; they decided to lower the relevant risk from 5% being highly sleep-disturbed to 3%. In doing so, the GDG referred to the WHO night noise guidelines (WHO, 2009), which concluded that while there was insufficient evidence that physiological effects at noise levels below 40 dB L_{night} are harmful to health, there were observed adverse health effects at levels starting from 40 dB L_{night} . At 40 dB, about 3–4%

(depending on the noise source) of the population still reported being highly sleep-disturbed due to noise, which was considered relevant to health. The GDG considered it important that this level is consistent with the previous health-based approach adopted by the WHO night noise guidelines, and agreed that the absolute risk associated with the guideline value selected should not exceed 3%HSD to be health protective.

For annoyance, which is considered a less serious health effect than self-reported sleep disturbance (as indicated by the respective DWs), the relevant risk remained at 10%HA. This means the absolute risk associated with the guideline value selected should be closest to, but not above 10%HA, to be health protective.

Cognitive impairment: reading and oral comprehension

Acquiring skills in reading and oral comprehension at a young age is important for further development: a delay in acquiring these skills can have an impact later in life (Wilson & Lonigan, 2010). This impact cannot be predicted very accurately, but the GDG considered a delay of one month a relevant absolute risk.

Permanent hearing impairment

The literature on hearing impairment as a result of occupational noise exposure is extensive. A noise exposure level beyond 80 dB during 40 years of working a 40 hour work week can give rise to permanent hearing impairment. Given that environmental exposure to noise is much lower than these levels and that noise-related hearing impairments are not reversible, the GDG considered that there should be no risk of hearing impairment due to environmental noise and considered any increased risk of hearing impairment relevant.

2.4.4 Strength of the recommendations

Finally, having determined the guideline exposure levels based on the ranking of prioritized health outcome measures, setting the strength of the recommendation was set as the final step of the guideline development process. This was also guided by the GRADE methodology (Alonso-Coello et al., 2016a; 2016b). According to this approach, strength of recommendation can be set as either strong or conditional (WHO, 2014c).

- A **strong** recommendation can be adopted as policy in most situations. The guideline is based on the confidence that the desirable effects of adherence to the recommendation outweigh the undesirable consequences. The quality of evidence for a net benefit – combined with information about the values, preferences and resources – inform this recommendation, which should be implemented in most circumstances.
- A **conditional** recommendation requires a policy-making process with substantial debate and involvement of various stakeholders. There is less certainty of its efficacy owing to lower quality of evidence of a net benefit, opposing values and preferences of individuals and populations affected or the high resource implications of the recommendation, meaning there may be circumstances or settings in which it will not apply.

The GRADE approach defines a number of parameters that should be assessed to determine the strength of recommendations: quality of evidence, balance of benefits and harms, values and preference related to the outcomes of interventions to exposure, resources implications, priority of the problem, equity and human rights, acceptability and feasibility (Box 2; Morgan et al., 2016).

Box 2 Parameters determining the strength of a recommendation

Quality of evidence further represents the confidence in the estimates of effect of the evaluated evidence, across outcomes critical and important to decision-making. The higher the quality of evidence, the greater the likelihood of a strong recommendation.

Balance of benefits and harms requires an evaluation of the absolute effects of both benefits and harms (or downsides) of the intervention or exposure and their importance. The greater net benefit or net harm associated with an intervention or an exposure, the greater the likelihood of a strong recommendation in favour or against an intervention or exposure.

Values and preferences related to the outcomes of an intervention or exposure set out the relative importance assigned to health outcomes by those affected by them; how such importance varies within and across populations; and whether this importance or variability is surrounded by uncertainty. The less uncertainty or variability there is about the values and preferences of people experiencing the critical or important outcomes, the greater the likelihood of a strong recommendation.

Resource implications take into consideration how resource-intensive and how cost-effective and substantially beneficial an intervention or exposure is. The more advantageous or clearly disadvantageous the resource implications are, the greater the likelihood of a strong recommendation either for or against the intervention or exposure.

The priority of the problem is determined by its importance and frequency (the burden of disease, disease prevalence or baseline risk). The greater the importance of the problem, the greater the likelihood of a strong recommendation.

Equity and human rights considerations are an important aspect of the process. The greater the likelihood that the intervention will reduce inequities, improve equity or contribute to the realization of one or several human rights as defined under the international legal framework, the greater the likelihood of a strong recommendation.

Acceptability plays a prominent role: the greater the acceptability of an option to all or most stakeholders, the greater the likelihood of a strong recommendation.

Feasibility overlaps with values and preferences, resource considerations, existing infrastructures, equity, cultural norms, legal frameworks and many other considerations. The greater the feasibility of an option from the standpoint of all or most stakeholders, the greater the likelihood of a strong recommendation.

The GDG evaluated the strength of the recommendations based on these parameters, following a two-step procedure. Initially, the strength of each recommendation was set as strong or conditional based on an assessment of the quality of evidence. The GDG then identified and assessed contextual

parameters that might have a contributory role (see Box 2 above). Based on this qualitative evaluation, the initial recommendation strength was either adapted or confirmed. It is important to note that while the initial parameter “quality of evidence” was informed by comprehensive systematic reviewing processes, the remaining contextual parameters were assessed by the informed qualitative expert judgement of the GDG.

Furthermore, the GDG agreed to decision-making rules, applied when formulating the recommendations. An evidence rating of low quality or very low quality would lead only to a conditional recommendation. Setting a strong recommendation was only considered if the evidence was at least moderate quality. The final recommendations were formulated based on the consideration of all the parameters and decision rules adopted by the GDG. A detailed exploration of all the recommendations is set out in Chapter 3.

2.5 Individuals and partners involved in the guideline development process

The process of WHO guideline development is conducted by several groups with clearly defined roles and responsibilities. Comprising WHO staff members, experts and stakeholders, these are the Steering Group, the GDG, the Systematic Review Team and the External Review Group.

The **Steering Group** includes WHO staff members with different affiliations but whose work experience is relevant to the topic of environmental noise and associated health outcomes. It is involved at all stages of planning, selecting members of the GDG and External Review Group, reviewing evidence and developing potential recommendations at the main expert meetings, as well as ongoing consultation on revisions following peer review. Details of the members of the Steering Group are listed in Table A1.1 in Annex 1.

The **GDG** consists of a group of content experts gathered to investigate all aspects of evidence contributing to the recommendations, including expertise in evidence-based guideline development. This Group defined the key questions and priorities of the research, chose and ranked outcomes and provided advice on any modifications of the scope as established by the Steering Group. The members also outlined the systematic review methods; appraised the evidence used to inform the guidelines; and advised on the interpretation of this evidence, with explicit consideration of the overall balance of benefits and harms. Ultimately the GDG formulated the final recommendations, taking into account the diverse values and preferences of individuals and populations affected. It also determined the strength of the results and responded to external peer reviews. The complete list of GDG members and their specific roles, affiliations and areas of expertise are listed in Table A1.2 in Annex 1.

The **Systematic Review Team** includes experts in the field of environmental health, commissioned by WHO staff to undertake systematic reviews of evidence. The GDG recommended a number of authors to conduct the evidence reviews and summary chapters, based on their expertise. Details of the members of the Systematic Review Team are included in Table A1.3 in Annex 1.

The **External Review Group** is composed of technical content experts and end-users as well as stakeholders, and is balanced geographically and by gender. The experts and end-users were selected for their expertise in the field, and the Group also included representatives of professional groups and industry associations, who will be implementing the guidelines. Members were asked to

review the material at different stages of the development process. The list of technical experts and stakeholders is provided in Tables A1.4 and A1.5, respectively, in Annex 1.

Management of conflict of interest is an integral part of WHO's guideline development procedure. All members of the GDG and authors of the evidence reviews completed WHO declaration of interest forms. These were reviewed by the WHO Secretariat for potential conflicts of interest. A number of conflicts of interest were declared in the forms, but following a standardized management review it was not found necessary to exclude any members of the GDG or authors from their respective roles. Members of the External Review Group (technical experts only) were also asked to complete the form when invited to participate.

In addition, at the start of the meeting of the GDG all members of the GDG received a briefing about the nature of all types of conflict of interest (financial, academic/intellectual and nonacademic) and were asked to declare to the meeting any conflicts they might have. No member of the GDG or the Systematic Review Team was excluded from his/her respective role. A summary of the conflict of interest management is presented in Annex 3.

The GDG set its own rules on how it would work and how contentious issues should be resolved – for instance, by means of a vote. The main decision-making mechanism involved reaching consensus; if a vote was required, the experts involved in developing the underlying evidence for the specific recommendation were excluded from voting, and an agreement was reached via a two thirds majority of the rest of the group.

2.6 Previously published WHO guidelines on environmental noise

Prior to this publication, WHO published community noise guidelines (CNG) in 1999 (WHO, 1999) and night noise guidelines for Europe (NNG) in 2009 (WHO Regional Office for Europe, 2009).

2.6.1 CNG

The scope of WHO's efforts to develop the CNG in 1999 was similar to that for the current guidelines. The objective was then formulated as: "to consolidate scientific knowledge of the time on the health impacts of community noise and to provide guidance to environmental health authorities and professionals trying to protect people from the harmful effects of noise in nonindustrial environments" (WHO, 1999). The guidelines were based on studies carried out up to 1995 and a few meta-analyses from some years later.

The health risk to humans from exposure to environmental noise was evaluated and guideline values derived. At that time WHO had not yet developed its guideline development process, on which the current guidelines are based (WHO, 2014c). The main differences in content are that the previous guidelines were expert-based and provided more global coverage and applicability, such as issues of noise assessment and control that were addressed in detail. They included a discussion on noise sources and measurement, including the basic aspects of source characteristics, sound propagation and transmission. Adverse health effects of noise were characterized, and combined noise sources and their effects were considered. Furthermore, the guidelines included discussions of strategies and priorities in the management of indoor noise levels, noise policies and legislation, environmental

noise impact and enforcement of regulatory standards; although there were no chapters on wind turbine noise and leisure noise.

2.6.2 NNG

In 2009 the WHO Regional Office for Europe published the NNG to provide scientifically based advice to Member States for the development of future legislation and policy action in the area of assessment and control of night noise exposure.

The NNG complement the previous CNG, incorporating the advancement of research on noise and sleep disturbance up to 2006. The working group of experts reviewed available scientific evidence on the health effects of night noise and derived health-based guideline values. Again, WHO had not yet introduced its evidence-based recommendations policy and the NNG were mainly expert-based. They considered the scientific evidence on the threshold of night noise exposure indicated by L_{night} as defined in the END (EC, 2002a), and the experts concluded that a L_{night} value of 40 dB should be the target of the NNG (for all sources) to protect the public, including the most vulnerable groups such as children, chronically ill and elderly people. Further, an L_{night} value of 55 dB was recommended as an interim target for countries that could not follow the guidelines in the short term for various reasons or where policy-makers chose to adopt a stepwise approach.

2.6.3 Differences from the prior noise guidelines

The current guidelines differ from the older ones, recommending levels of exposure unlike those previously outlined (especially by the NNG). The following major differences between the previous and current guidelines explain the novel set of recommended values.

- The development process for the current guidelines adhered to a new, rigorous, evidence-based methodology, as outlined in the WHO handbook for guideline development (WHO, 2014c). WHO adopted these internationally recognized standards to ensure high methodological quality and a transparent, evidence-based decision-making process in the guideline development.
- The current guidelines consider cardiovascular disease a critical health outcome measure.
- They also consider a broader set of health outcomes, including adverse birth outcomes, diabetes, obesity and mental well-being. Wherever applicable, incidence, prevalence and mortality were considered separately.
- The current guidelines cover two new noise sources: wind turbines and leisure noise.
- Critical and important health outcomes are considered separately for each of the noise sources.
- The guideline development process included the health effects of intervention measures to mitigate noise exposure from different noise sources for the first time.
- The style of recommendations differs: the current guidelines include an exact exposure value for every health outcome regarded as critical, for each noise source. Guideline recommendation values were set for each of the noise sources separately, based on the exact exposure values and a prioritization scheme, developed with the help of DWs.
- The current guidelines apply a 1 dB increment scheme, whereas prior guidelines (CNG and NNG) formulated or presented recommendations in 5 dB steps.

- In comparison to the 1999 CNG, which defined environment-specific exposure levels, the current guidelines are source specific. They recommend values for outdoor exposure to road traffic, railway, aircraft and wind turbine noise, and indoor as well as outdoor exposure levels for leisure noise.
- Except for leisure noise, all exposure levels recommended in the current guidelines are average sound pressure levels for outdoor exposure.
- The current guidelines make use of the noise indices defined in the END: L_{den} and L_{night} .

The definition of “community noise” used in the CNG in 1999 was also adapted. The GDG agreed to use the term “environmental noise” instead, and offered an operational definition of: “noise emitted from all sources except sources of occupational noise exposure in workplaces”.

The current environmental noise guidelines for the European Region supersede the CNG from 1999. Nevertheless, the GDG recommends that all CNG indoor guideline values and any values not covered by the current guidelines (such as industrial noise and shopping areas) should remain valid.

Furthermore, the current guidelines complement the NNG from 2009. Two main aspects of the NNG constitute this complementarity: the different guiding principles and the comprehensive investigation of the immediate physiological effects of environmental noise on sleep. As guiding principles the NNG defined effect thresholds or “lowest observed adverse health effect levels” for both immediate physiological reactions during sleep (i.e. awakening reactions or body movements during sleep) and long-term adverse health effects (i.e. self-reported sleep disturbance). These guideline exposure levels defined a level below which no effects were expected to occur (corresponding to 30 dB L_{night}) and proceeded to define the level where adverse effects start to occur (corresponding to 40 dB L_{night}), with the aim of protecting the whole population, including – to some extent – vulnerable groups. The development of the NNG values relied on evidence-based expert judgement. In contrast, the current guidelines formulate recommendations more strictly based on the available evidence and following the guiding principle to identify exposure values based on a relevant risk increase of adverse health effects. Thus, the recommended guideline values might not lead to full protection of the population, including all vulnerable groups. The GDG stresses that the aim of the current guidelines is to define an exposure level at which effects certainly begin.

Secondly, the NNG comprehensively investigate the immediate short-term effects of environmental noise during sleep, including physiological reactions such as awakening reactions and body movements. They also provided threshold information about single-event noise indicators (such as the $L_{A,\text{max}}$). In contrast, the current guideline values for the night time are only based on the prevalence of self-reported sleep disturbance and do not take physiological effects into account. The causal link between immediate physiological reactions and long-term adverse health effects is complex and difficult to prove. Thus, the current guidelines are restricted to long-term health effects during night time and therefore only include recommendations about average noise indicators: L_{night} . Nevertheless, the evidence review on noise and sleep (Basner & McGuire, 2018) includes an overview of single-event exposure–effect relationships.

3. Recommendations

This chapter presents specific recommendations on guideline exposure levels and/or interventions to reduce exposure and/or improve health for individual sources of noise: road traffic, railway, aircraft, wind turbines and leisure noise. The strength of each recommendation is provided (strong or conditional) and a short rationale for how each of the guideline levels was achieved is given.

The GDG discussed extensively the best way to present guideline exposure levels – either as the exact values or in 5 dB steps – and the approach to rounding the values to the nearest integer. The 5 dB increment, rounded down from the exact exposure value to the nearest 5 dB level, was initially chosen as being commonly applied in noise legislation and used in prior guidelines (WHO, 1999; EC, 2002a; WHO Regional Office for Europe, 2009). It was also used to meet the principle of precaution, since imprecision in the exposure assessment in the field of epidemiology tends to attenuate the actual effects in the population.

Use of 5 dB increments resulted in uneven magnitude of rounding down, however, raising concerns of arbitrariness. It became apparent that inclusion of both exact values and the 5 dB rounded-down values might be confusing and could affect the applicability of the guidelines. Hence, the GDG ultimately decided that formulating recommendations based on the exact calculated values, rounded only to the nearest integer, would ensure more clarity and transparency. Furthermore, it noted that adhering to a 5 dB roster might not reflect the progress in the precision of exposure assessment methods in recent decades, which would justify application of a 1 dB step.

The GDG acknowledged that the recommendations might be presented as the exact guideline exposure levels only, leaving the use of 5 dB bands to the potential policy decisions to formulate or revise noise legislation, which are beyond the scope of this publication. The WHO guideline values are public health-oriented recommendations, based on scientific evidence on health effects and on an assessment of achievable noise levels. They are strongly recommended and as such should serve as the basis for a policy-making process in which policy options are quantified and discussed. It should be recognized that in that process additional considerations of costs, feasibility, values and preferences should also feature in decision-making when choosing reference values such as noise limits for a possible standard or legislation.

In addition to the source-specific recommendations in the following sections, a short rationale for the decision-making process by the GDG for developing a particular recommendation is provided, as well as an overview of the evidence considered. This includes a recapitulation of the specific PICOS/PECCOS question (see section 2.3.1), along with a summary of evidence for each of the critical and important health effects from exposure to each of the noise sources, and for the effectiveness of interventions.

Furthermore, a description is provided of the other factors considered according to the GRADE dimensions for the assessment of the strength of recommendations (see section 2.4.4). While the quality of evidence is central to determining this, the process of moving from evidence to recommendations involves several other considerations. These include values and preferences, balance of benefits and harms, consideration of the priority of the problem, resource implications, equity and human rights aspects, acceptability and feasibility (WHO, 2014c).



3.1 Road traffic noise

Recommendations

For average noise exposure, the GDG **strongly** recommends reducing noise levels produced by road traffic below **53 dB L_{den}** , as road traffic noise above this level is associated with adverse health effects.

For night noise exposure, the GDG **strongly** recommends reducing noise levels produced by road traffic during night time below **45 dB L_{night}** , as road traffic noise above this level is associated with adverse effects on sleep.

To reduce health effects, the GDG **strongly** recommends that policy-makers implement suitable measures to reduce noise exposure from road traffic in the population exposed to levels above the guideline values for average and night noise exposure. For specific interventions, the GDG recommends reducing noise both at the source and on the route between the source and the affected population by changes in infrastructure.

3.1.1 Rationale for the guideline levels for road traffic noise

The exposure levels were derived in accordance with the prioritization process of critical health outcomes described in section 2.4.3. For each of the outcomes, the exposure level was identified by applying the benchmark, set as relevant risk increase to the corresponding ERF. In the case of exposure to road traffic noise, the process can be summarized as follows (Table 6).

Table 6. Average exposure levels (L_{den}) for priority health outcomes from road traffic noise

Summary of priority health outcome evidence	Benchmark level	Evidence quality
Incidence of IHD The 5% relevant risk increase occurs at a noise exposure level of 59.3 dB L_{den} . The weighted average of the lowest noise levels measured in the studies was 53 dB L_{den} and the RR increase per 10 dB is 1.08.	5% increase of RR	High quality
Incidence of hypertension One study met the inclusion criteria. There was no significant increase of risk associated with increased noise exposure in this study.	10% increase of RR	Low quality
Prevalence of highly annoyed population There was an absolute risk of 10% at a noise exposure level of 53.3 dB L_{den} .	10% absolute risk	Moderate quality
Permanent hearing impairment	No increase	No studies met the inclusion criteria
Reading skills and oral comprehension in children	One-month delay	Very low quality

In accordance with the prioritization process (see section 2.4.3), the GDG set a guideline exposure level of 53.3 dB L_{den} for average exposure, based on the relevant increase of the absolute %HA. It was confident that there was an increased risk for annoyance below this noise exposure level, but probably no increased risk for other priority health outcomes. In accordance with the defined rounding procedure, the value was rounded to 53 dB L_{den} . As the evidence on the adverse effects of road traffic noise was rated moderate quality, the GDG made the recommendation strong.

Next, the GDG assessed the evidence for night noise exposure and its effect on sleep disturbance (Table 7).

Table 7. Night-time exposure levels (L_{night}) for priority health outcomes from road traffic noise

Summary of priority health outcome evidence	Benchmark level	Evidence quality
Sleep disturbance 3% of the participants in studies were highly sleep-disturbed at a noise level of 45.4 dB L_{night}	3% absolute risk	Moderate quality

Based on the evidence of the adverse effects of road traffic noise on sleep disturbance, the GDG defined a guideline exposure level of 45.4 dB L_{night} . The exact exposure value was rounded to 45 dB L_{night} . As the evidence was rated moderate quality, the GDG made the recommendation strong.

The GDG also considered the evidence for the effectiveness of interventions. The results showed that:

- addressing the source by improving the choice of appropriate tyres, road surface, truck restrictions or by lowering traffic flow can reduce noise exposure;
- path interventions such as insulation and barrier construction reduce noise exposure, annoyance and sleep disturbance;
- changes in infrastructure such as construction of road tunnels lower noise exposure, annoyance and sleep disturbance;
- other physical interventions such as the availability of a quiet side of the residence reduce noise exposure, annoyance and sleep disturbance.

Given that it is possible to reduce noise exposure and that best practices already exist for the management of noise from road traffic, the GDG made a strong recommendation.

3.1.1.1 Other factors influencing the strength of recommendations

Other factors considered in the context of recommendations on road traffic noise included those related to values and preferences, benefits and harms, resource implications, equity, acceptability and feasibility; moreover, nonpriority health outcomes (the incidence of stroke and diabetes) were considered. Ultimately, the assessment of all these factors did not lead to a change in the strength of the recommendations. Further details are provided in section 3.1.2.3.

3.1.2 Detailed overview of the evidence

The following sections provide a detailed overview of the evidence constituting the basis for setting the recommendations on road traffic noise. It is presented and summarized separately for each of the critical health outcomes, and the GDG's judgement of the quality of evidence is indicated (for a detailed overview of the evidence on important health outcomes, see Annex 4). Research into health outcomes and effectiveness of interventions is addressed consecutively.

A comprehensive summary of all evidence considered for each of the critical and important health outcomes can be found in the eight systematic reviews published in the *International Journal of Environmental Research and Public Health* (see section 2.3.2 and Annex 2).



3.1.2.1 Evidence on health outcomes

The key question posed was: in the general population exposed to road traffic noise, what is the exposure–response relationship between exposure to road traffic noise (reported as various noise indicators) and the proportion of people with a validated measure of health outcome, when adjusted for main confounders? A summary of the PICOS/PECCOS scheme applied (see section 2.3.1) and the main findings is set out in Tables 8 and 9.

Table 8. PICOS/PECCOS scheme of critical health outcomes for exposure to road traffic noise

PECO	Description
Population	General population
Exposure	Exposure to high levels of noise produced by road traffic (average/night time)
Comparison	Exposure to lower levels of noise produced by road traffic (average/night time)
Outcome(s)	For average noise exposure: 1. cardiovascular disease 2. annoyance 3. cognitive impairment 4. hearing impairment and tinnitus 5. adverse birth outcomes 6. quality of life, well-being and mental health 7. metabolic outcomes For night noise exposure: 1. effects on sleep

Table 9. Summary of findings for health effects from exposure to road traffic noise (L_{den})

Noise metric	Priority health outcome measure	Quantitative risk for adverse health	Lowest level of exposure across studies	Number of participants (studies)	Quality of evidence
Cardiovascular disease					
L_{den}	Incidence of IHD	RR = 1.08 (95% confidence interval (CI): 1.01–1.15) per 10 dB increase	53 dB	67 224 (7)	High (upgraded for dose-response)
L_{den}	Incidence of hypertension	RR = 0.97 (95% CI: 0.90–1.05) per 10 dB increase	N/A	32 635 (1)	Low (downgraded for risk of bias and because only one study was available)
Annoyance					
L_{den}	%HA	Odds ratio (OR) = 3.03 (95% CI: 2.59–3.55) per 10 dB increase	40 dB	34 112 (25)	Moderate (downgraded for inconsistency)
Cognitive impairment					
L_{den}	Reading and oral comprehension	Not estimated	N/A	Over 2844 (1)	Very low (downgraded for inconsistency)
Hearing impairment and tinnitus					
L_{den}	Permanent hearing impairment	–	–	–	–

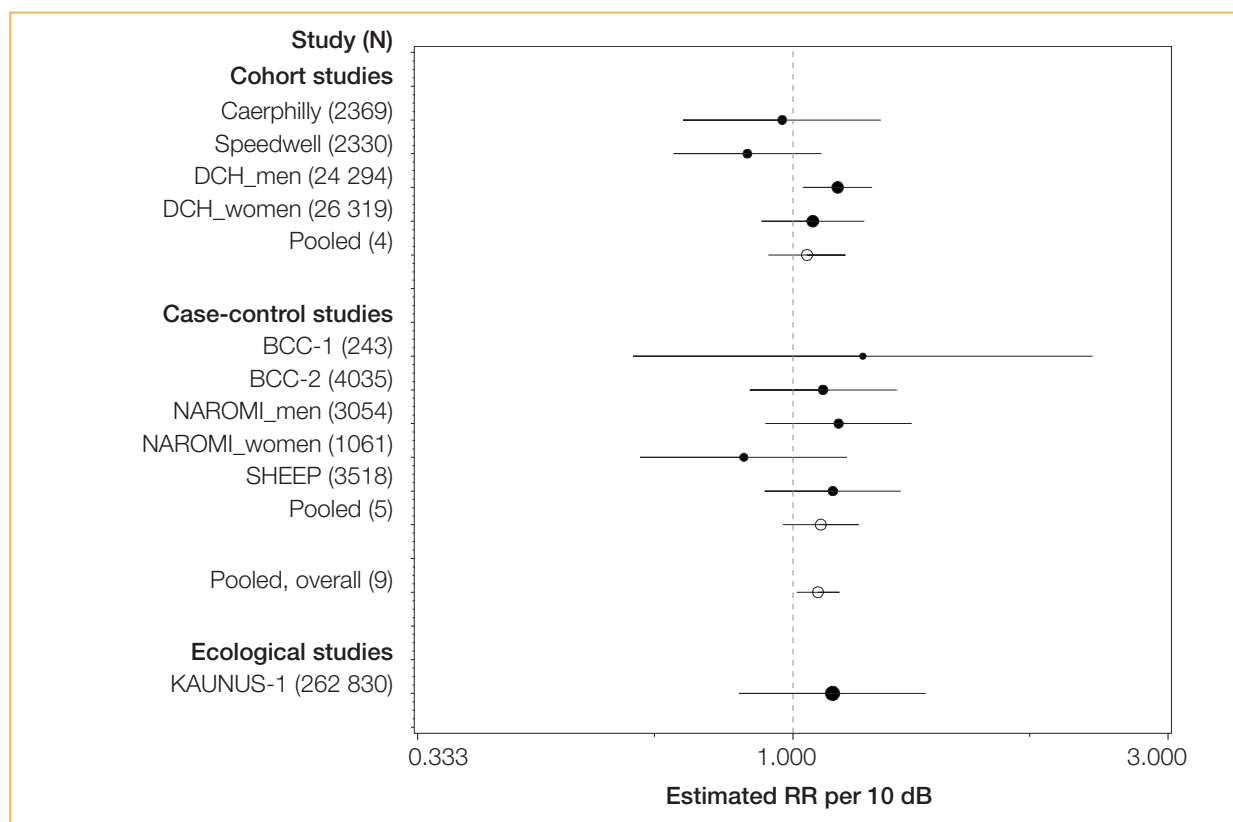
Cardiovascular disease

IHD

A total of three cohort (Babisch & Gallacher, 1990; Babisch et al., 1988; 1993a; 1993b; 1999; 2003; Caerphilly and Speedwell Collaborative Group, 1984; Sørensen et al., 2012a; 2012c) and four case-control studies (Babisch, 2004; Babisch et al., 1992; 1994; 2005a; Selander et al., 2009; Wiens, 1995) investigated the relationship between road traffic noise and the incidence of IHD. These involved a total of 67 224 participants, including 7033 cases. As identified in Fig. 1, the overall RR derived from the meta-analysis was 1.08 (95% CI: 1.01–1.15) per 10 dB L_{den} increase in noise levels, across a noise range of 40 dB to 80 dB. This evidence was rated high quality.

The data were supported by one ecological study conducted with 262 830 participants, including 418 cases, which also reported a statistically significant estimate (Grazuleviciene et al., 2004; Lekaviciute, 2007). In this study, a positive but nonsignificant association was found: RR of 1.12 (95% CI: 0.85–1.48) per 10 dB L_{den} increase in noise. This evidence was rated very low quality.

Fig. 1. The association between exposure to road traffic noise (L_{den}) and incidence of IHD

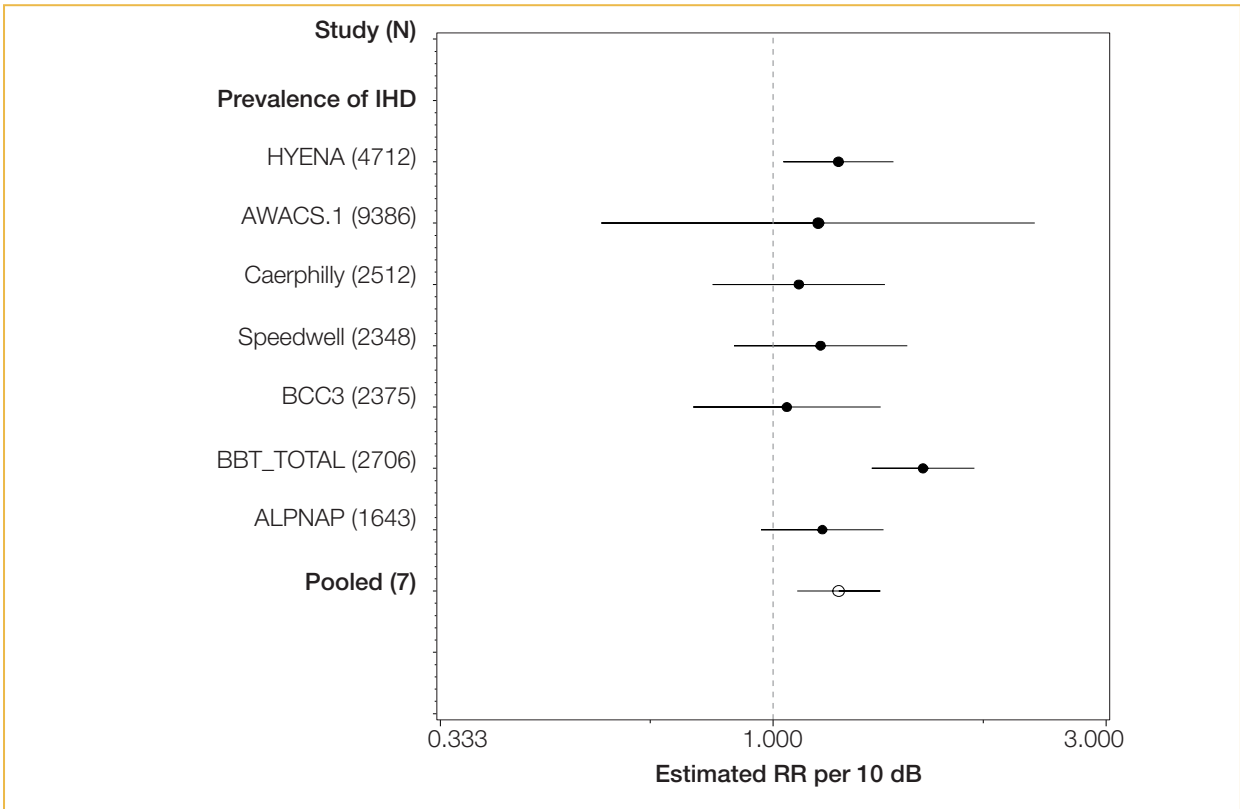


Notes: The dotted vertical line corresponds to no effect of exposure to road traffic noise. The black circles correspond to the estimated RR per 10 dB and 95% CI. The white circles represent the pooled random effect estimates and 95% CI. For further details on the studies included in the figure please refer to the systematic review on environmental noise and cardiovascular and metabolic effects (van Kempen et al., 2018).



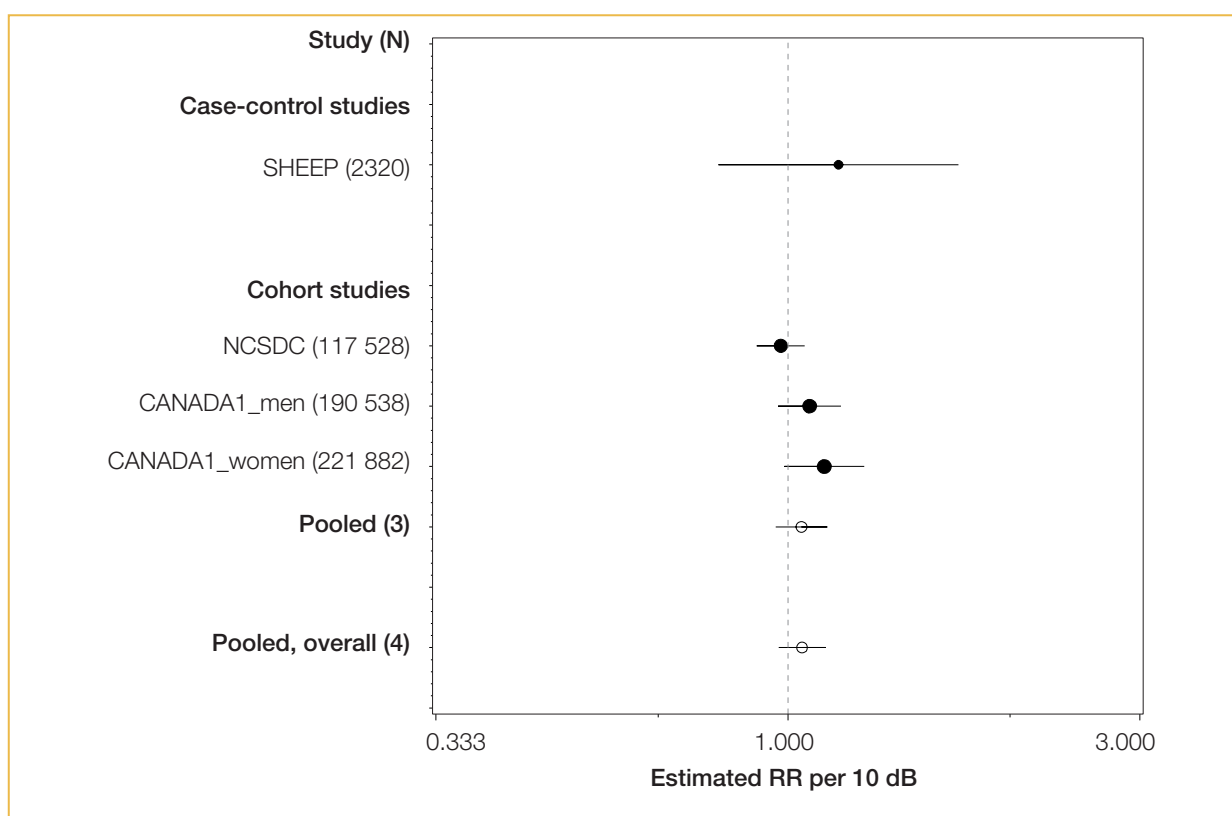
Furthermore, additional evidence was available from eight cross-sectional studies that investigated the relationship between road traffic noise and prevalence of IHD (Babisch & Gallacher, 1990; Babisch et al., 1988; 1992; 1993a; 1993b; 1994; 1999; 2003; 2005a; 2008; 2012a; 2012b; Caerphilly and Speedwell Collaborative Group, 1984; Floud et al., 2011; 2013a; 2013b; Heimann et al., 2007; Jarup et al., 2005; 2008; Lercher et al., 2008; 2011; van Poll et al., 2014; Wiens, 1995). These studies involved a total of 25 682 participants, including 1614 cases. The overall RR was 1.24 (95% CI: 1.08–1.42) per 10 dB L_{den} increase in road traffic noise levels. The range in noise levels in the studies under evaluation was 30–80 dB. The results of the meta-analysis are presented in Fig. 2. This evidence was rated low quality.

Fig. 2. The association between exposure to road traffic noise (L_{den}) and prevalence of IHD



Notes: The dotted vertical line corresponds to no effect of exposure to road traffic noise. The black circles correspond to the estimated RR per 10 dB and 95% CI. The white circle represents the pooled random effect estimates and 95% CI. For further details on the studies included in the figure please refer to the systematic review on environmental noise and cardiovascular and metabolic effects (van Kempen et al., 2018).

Mortality from IHD was also investigated in one case-control (Selander et al., 2009) and two cohort studies (Beelen et al., 2009; Gan et al., 2012), which involved 532 268 participants, including 6884 cases. The quantitative relationship between road traffic noise and mortality from IHD was RR = 1.05 (95% CI: 0.97–1.13) per 10 dB L_{den} increase in noise levels (see Fig. 3). This evidence was rated moderate quality.

Fig. 3. The association between exposure to road traffic noise (L_{den}) and mortality from IHD

Notes: The dotted vertical line corresponds to no effect of exposure to road traffic noise. The black circles correspond to the estimated RR per 10 dB and 95% CI. The white circles represent the pooled random effect estimates and 95% CI. For further details on the studies included in the figure please refer to the systematic review on environmental noise and cardiovascular and metabolic effects (van Kempen et al., 2018).

Hypertension

One cohort study into the relationship between road traffic noise and incidence of hypertension was identified; it involved 32 635 participants, including 3145 cases (Sørensen et al., 2011; 2012c). The study found a nonsignificant effect size of 0.97 (95% CI: 0.90–1.05) per 10 dB L_{den} increase in noise levels, which does not support an increased risk of hypertension due to exposure to road traffic noise. Because of the risk of bias and the availability of only one study, this evidence was rated low quality.

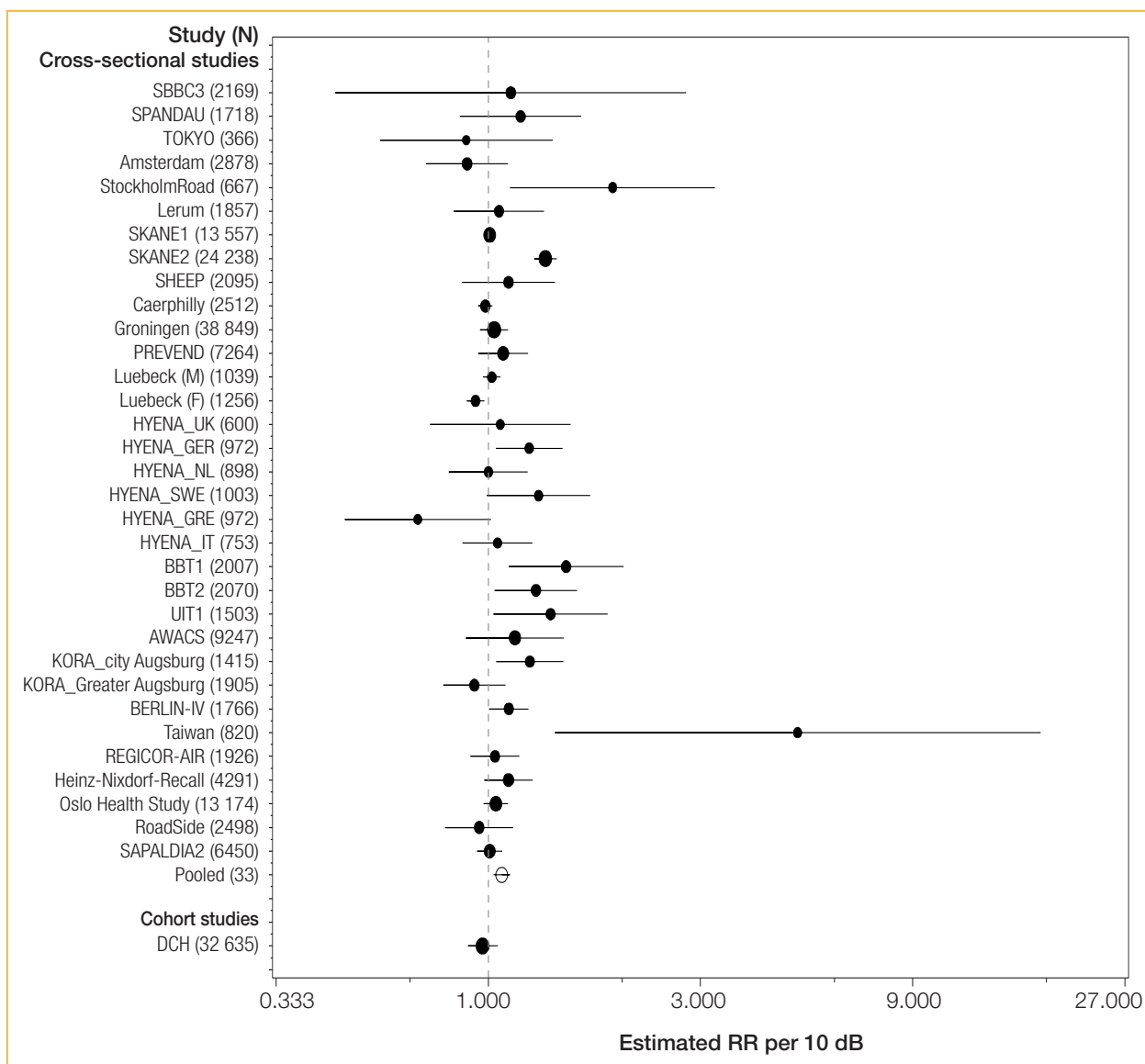
In addition, 26 cross-sectional studies were identified that looked at the association between road traffic noise and prevalence of hypertension (Babisch et al., 1988; 1992; 1994; 2005a; 2008; 2012a; 2012b; 2013a; 2013b; 2014b; 2014c; Barregard et al., 2009; Bjork et al., 2006; Bluhm et al., 2007; Bodin et al., 2009; Caerphilly and Speedwell Collaborative Group, 1984; Chang et al., 2011; 2014; de Kluizenaar et al., 2007a; 2007b; Dratva et al., 2012; Eriksson et al., 2012; Foraster et al., 2011; 2012; 2013; 2014a; 2014b; Fuks et al., 2011; Hense et al., 1989; Herbold et al., 1989; Jarup et al., 2005; 2008; Knipschild et al., 1984; Lercher et al., 2008; 2011; Maschke, 2003; Maschke & Hecht,



2005; Maschke et al., 2003; Oftedal et al., 2011; 2014; Selander et al., 2009; van Poll et al., 2014; Wiens, 1995; Yoshida et al., 1997). In total, these studies involved 154 398 participants, including 18 957 cases. The overall RR for prevalence of hypertension was 1.05 (95% CI: 1.02–1.08) per 10 dB L_{den} increase in noise levels. The noise range of the studies under evaluation was 20–85 dB. The overall evidence was rated very low quality.

Fig. 4 shows the association between road traffic noise and incidence and prevalence of hypertension.

Fig. 4. The association between exposure to road traffic noise (L_{den}) and hypertension



Notes: The dotted vertical line corresponds to no effect of exposure to road traffic noise. The black dots correspond to the estimated RR per 10 dB and 95% CI. The white circle represents the summary estimate and 95% CI. For further details on the studies included in the figure please refer to the systematic review on environmental noise and cardiovascular and metabolic effects (van Kempen et al., 2018).

Stroke

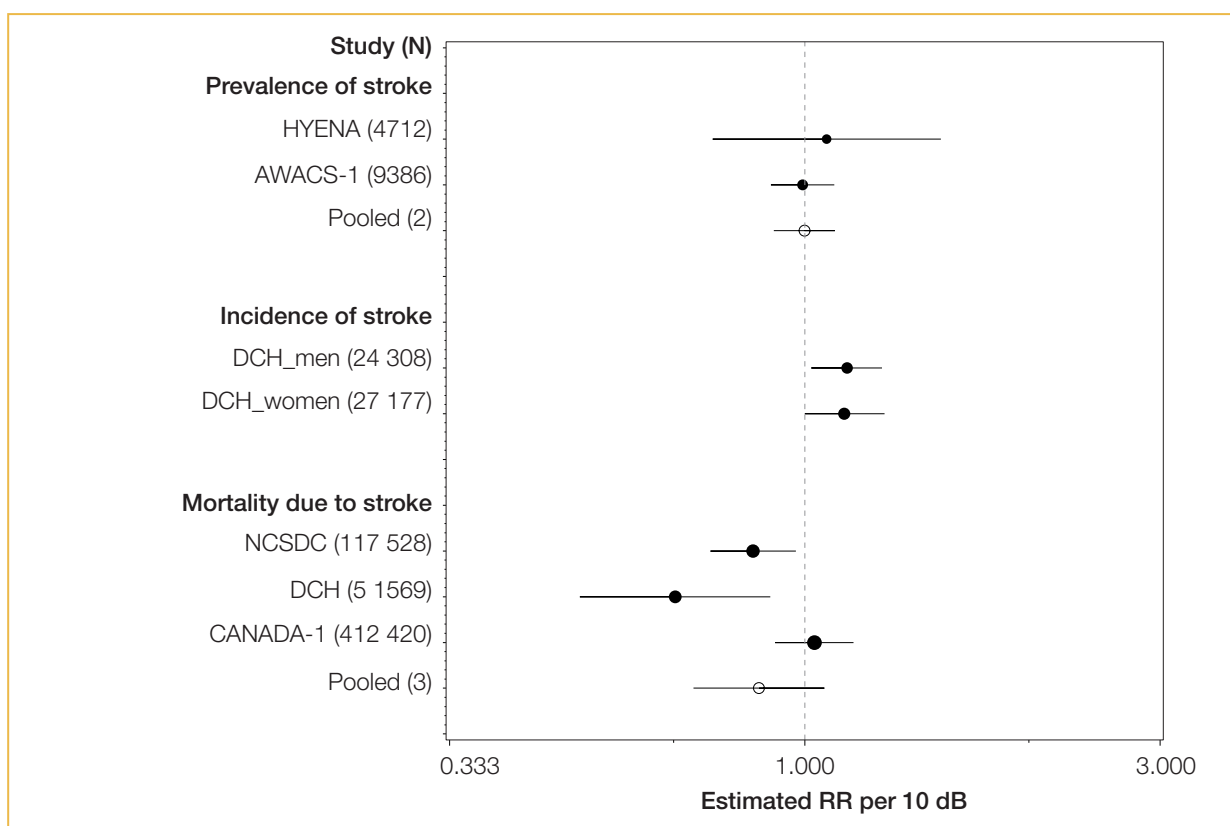
One cohort study into the relationship between road traffic noise and incidence of stroke was identified (Sørensen et al., 2011; 2012b; 2014). It involved 51 485 participants, including 1881 cases, and found an RR of 1.14 (95% CI: 1.03–1.25) per 10 dB L_{den} increase in noise levels, across a range of around 50–70 dB. The evidence was rated moderate quality.

Two cross-sectional studies on road traffic noise and prevalence of stroke involved 14 098 participants, including 151 cases (Babisch et al., 2005a; 2008; 2012a; 2012b; 2013a; Floud et al., 2011; 2013a; 2013b; Jarup et al., 2005; 2008; van Poll et al., 2014) yielded an estimated RR of 1.00 (95% CI: 0.91–1.10) per 10 dB L_{den} increase in noise levels. This evidence was rated very low quality.

Furthermore, three cohort studies investigated the relationship between road traffic noise and mortality due to stroke (Beelen et al., 2009; Gan et al., 2012; Sørensen et al., 2011; 2012b; 2014). These involved 581 517 participants, including 2634 cases, and their pooled estimate was a statistically nonsignificant RR = 0.87 (95% CI: 0.71–1.06) per 10 dB L_{den} increase in road traffic noise levels. This evidence was rated moderate quality.

Fig. 5 presents the results of the meta-analysis for road traffic noise and measures of stroke.

Fig. 5. The association between exposure to road traffic noise (L_{den}) and stroke



Notes: The dotted vertical line corresponds to no effect of exposure to road traffic noise. The black dots correspond to the estimated RR per 10 dB and 95% CI. The white circles represent the summary estimate and 95% CI. For further details on the studies included in the figure please refer to the systematic review on environmental noise and cardiovascular and metabolic effects (van Kempen et al., 2018).

Children's blood pressure

Six cross-sectional studies investigated the change in systolic and diastolic blood pressure in children exposed to road traffic noise in residential settings (Belojevic & Evans, 2011; 2012; Bilenko et al., 2013; Liu et al., 2013; 2014; Regecova & Kelleroval, 1995; van Kempen et al., 2006). In total, 4197 children were included in these studies; the number of cases was not reported. For each increase in 10 dB L_{den} in noise levels, there was a statistically nonsignificant increase in systolic and in diastolic blood pressure of 0.08 mmHg (95% CI: -0.48–0.64) and 0.47 mmHg (95% CI: -0.30–1.24), respectively. The overall evidence was rated very low quality.

Furthermore, five cross-sectional studies investigated the association between systolic and diastolic blood pressure in children and exposure to road traffic noise in educational settings (Belojevic & Evans, 2011; 2012; Bilenko et al., 2013; Clark et al., 2012; Paunovic et al., 2013; Regecova & Kelleroval, 1995; van Kempen et al., 2006). In total, 4520 children were included in these studies; the number of cases was not reported. Systolic blood pressure decreased statistically nonsignificantly, at -0.60 mm (95% CI: -1.51–0.30) per 10 dB L_{den} increase in road traffic noise levels. Diastolic blood pressure increased statistically nonsignificantly, at 0.46 mm (95% CI: -0.60–1.53) per 10 dB L_{den} increase in road traffic noise levels. For both relationships, the evidence was rated very low quality.

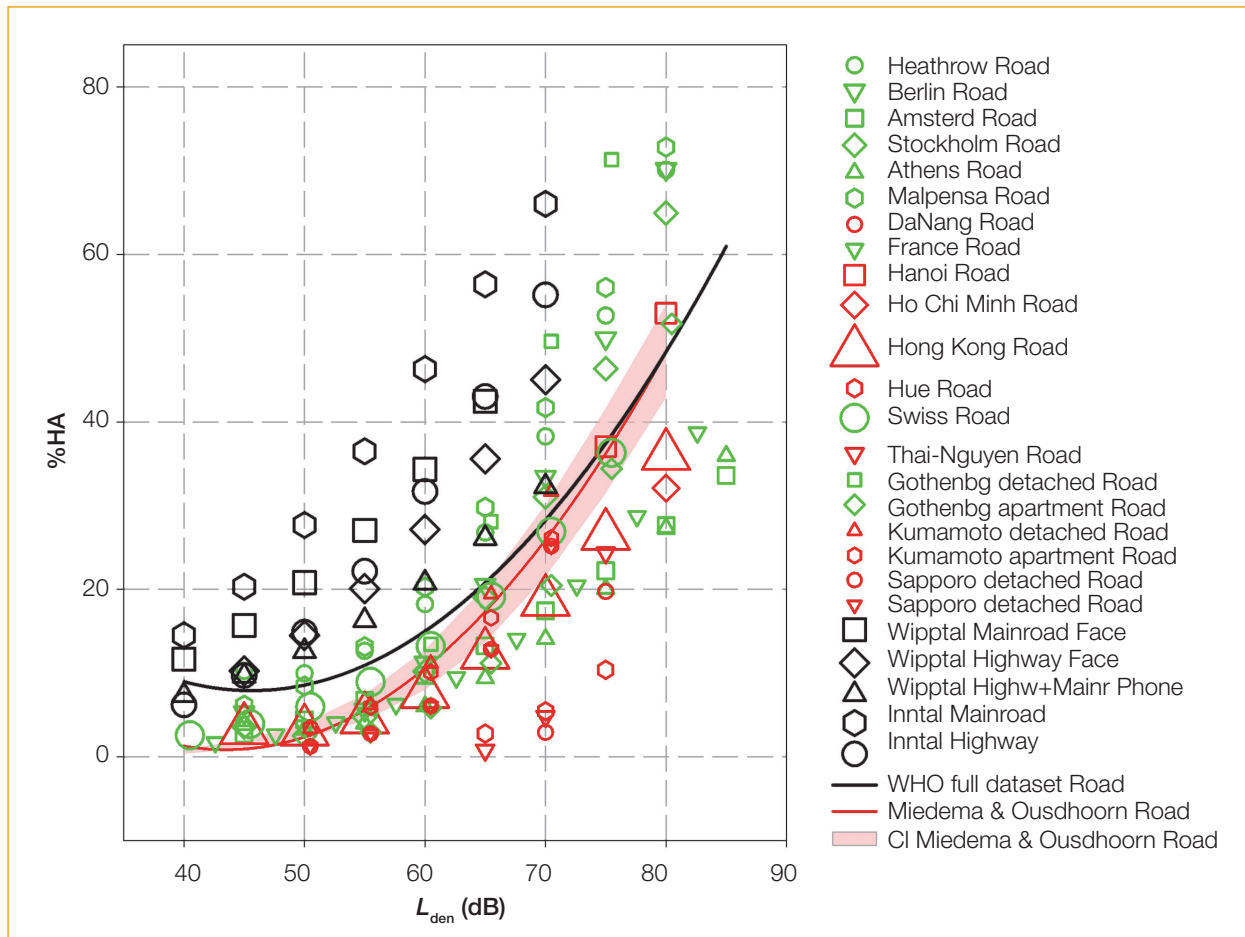
Annoyance

A vast amount of research proves the association between road traffic noise and annoyance. In total, 17 road traffic noise studies were identified that were used to model ERFs of the relationship between L_{den} and %HA (Babisch et al., 2009; Brink, 2013; Brink et al., 2016; Brown et al., 2014; 2015; Champelovier et al., 2003; Heimann et al., 2007; Lercher et al., 2007; Medizinische Universitaet Innsbruck, 2008; Nguyen et al., 2012a; Pierette et al., 2012; Sato et al., 2002; Shimoyama et al., 2014). These incorporated data from 34 112 study participants. The estimated data points of each of the studies are plotted in Fig. 6, alongside an aggregated ERF including the data from all the individual studies (see the black line for “WHO full dataset”). The lowest category of noise exposure considered in any of the studies, and hence included in the systematic review, is 40 dB, corresponding to approximately 9%HA. The benchmark level of 10%HA is reached at 53.3 dB L_{den} (see Fig 6).

Table 10 shows the %HA in relation to exposure to road traffic noise. The calculations are based on the regression equation $\%HA = 78.9270 - 3.1162 \times L_{den} + 0.0342 \times L_{den}^2$ derived from the systematic review (Guski et al., 2017). Even though there is a large evidence base substantiating the association of average road traffic noise and noise annoyance, the overall evidence had to be rated low quality. The main reasons for downgrading included limitations regarding the acoustical data provided, the nature of study design (most of the studies in the realm of annoyance research follow a cross-sectional approach), the inconsistency of results and the variety in the questions asked.

Nevertheless, the general quality of the evidence was substantiated with the help of additional statistical analyses that apply classic health outcome measures to estimate noise annoyance. When comparing road traffic noise exposure at 50 dB and 60 dB, the analyses revealed evidence rated moderate quality for an association between road traffic noise and %HA for an increase per 10 dB (OR = 2.74; 95% CI: 1.88–4.00). Moreover, there was evidence rated high quality for the increase of %HA per 10 dB increase in sound exposure, when data on all sound classes were included (OR = 3.03; 95% CI: 2.59–3.55).

Fig. 6. Scatterplot and quadratic regression of the relationship between road traffic noise (L_{den}) and annoyance (%HA)



Notes: The ERF by Miedema & Oudshoorn (2001) is added in red for comparison.

The size of the data points corresponds to the number of participants in the respective study ($\text{size} = \text{SQRT}(N)/10$).

If two results from different studies fall on the same data point, the last point plotted may mask the former one.

The black curve is derived from aggregated secondary data, while the red one is derived from individual data.

There is no indication of 95% CIs of the WHO full dataset, as a weighting based on the total number of participants for each 5 dB L_{den} sound class could not be calculated; weighting based on all participants of all sound classes proved to be unsuitable. The range of data included is illustrated by the distribution of data points.

For further details on the studies included in the figure please refer to the systematic review on environmental noise and annoyance (Guski et al., 2017).

Table 10. The association between exposure to road traffic noise (L_{den}) and annoyance (%HA)

L_{den} (dB)	%HA
40	9.0
45	8.0
50	8.6
55	11.0
60	15.1
65	20.9
70	28.4
75	37.6
80	48.5

Cognitive impairment

Evidence rated very low quality was available for the association between road traffic noise and reading and oral comprehension, assessed by tests. The review identified two papers that reported the results of the cross-sectional road traffic and aircraft noise exposure and children's cognition and health (RANCH) study, which examined exposure–effect relationships (Clark et al., 2006; Stansfeld et al., 2005). The study of over 2000 children aged 9–10 years, attending 89 schools around three major airports in the Netherlands, Spain and the United Kingdom did not find an exposure–effect relationship between road traffic noise exposure at primary school, which ranged from 31 to 71 dB $L_{Aeq,16h}$, and children's reading comprehension.

Few studies have investigated other health outcome measures related to cognition. Evidence rated low quality was available for an association between road traffic noise and cognitive impairment assessed through standardized tests (Cohen et al., 1973; Lukas et al., 1981; Pujol et al., 2014; Shield & Dockrell, 2008). There was evidence rated very low quality for an association between road traffic noise and long-term memory (Matheson et al., 2010; Stansfeld et al., 2005). No studies examined effects on short-term memory.

There was evidence rated very low quality, however, that road traffic noise does not have a considerable effect on children's attention (Cohen et al., 1973; Stansfeld et al., 2005). Further, there was evidence rated low quality that road traffic noise does not have a substantial effect on executive function (working memory), with studies consistently reporting no association (Clark et al., 2012; Matheson et al., 2010; Stansfeld et al., 2005; van Kempen et al., 2010; 2012).

Hearing impairment and tinnitus

No studies were found, and therefore no evidence was available for the association between road traffic noise and hearing impairment and tinnitus.

Sleep disturbance

For road traffic noise and self-reported sleep outcomes (awakenings from sleep, the process of falling asleep and sleep disturbance), 12 studies were identified that included a total of 20 120

participants (Bodin et al., 2015; Brown et al., 2015; Hong et al., 2010; Phan et al., 2010; Ristovska et al., 2009; Sato et al., 2002; Shimoyama et al., 2014); these were cross-sectional studies, conducted in healthy adults. The health outcome was measured by self-reporting via general health and noise surveys that included questions about sleep in general, and other questions about how noise affects sleep (see Table 11).

Table 11. Summary of findings for health effects from exposure to road traffic noise (L_{night})

Noise metric	Priority health outcome measure	Quantitative risk for adverse health	Lowest level of exposure across studies	Number of participants (studies)	Quality of evidence
Effects on sleep					
L_{night}	%HSD	OR: 2.13 (95% CI: 1.82–2.48) per 10 dB increase	43 dB	20 120 (12)	Moderate (downgraded for study limitations, inconsistency; upgraded for dose-response, magnitude of effect)

The model in the systematic review (Basner & McGuire, 2018) was based on outdoor L_{night} levels between 40 dB and 65 dB only; 40 dB was chosen as the lower limit because of possible inaccuracies of predicting lower noise levels. The range of noise exposure reported in the studies reviewed was 37.5–77.5 dB L_{night} . About 2% (95% CI: 0.90–3.15) of the population was characterized as highly sleep-disturbed at L_{night} levels of 40 dB. The %HSD at other, higher levels of road traffic noise is presented in Table 12. The association between road traffic noise and the probability of being highly sleep-disturbed was OR: 2.13 (95% CI: 1.82–2.48) per 10 dB increase in noise. This evidence was rated moderate quality.

Table 12. The association between exposure to road traffic noise (L_{night}) and sleep disturbance (%HSD)

L_{night} (dB)	%HSD	95% CI
40	2.0	0.9–3.15
45	2.9	1.40–4.44
50	4.2	2.14–6.27
55	6.0	3.19–8.84
60	8.5	4.64–12.43
65	12.0	6.59–17.36

Additional analyses were conducted for other health outcome measures related to sleep, which provided supporting evidence on the overall relationship between road traffic noise and sleep disturbance. When the noise source was not specified in the question, the relationship between road traffic noise and self-reported sleep outcomes was still positive but no longer statistically significant, with an OR of 1.09 (95% CI: 0.94–1.27) per 10 dB increase (Bodin et al., 2015; Brink, 2011; Frei et al., 2014; Halonen et al., 2012). This evidence was rated very low quality.



There was evidence rated moderate quality for an association between road traffic noise and sleep outcomes measured with polysomnography (probability of additional awakenings) with an OR of 1.36 (95% CI: 1.19–1.55) per 10 dB increase in indoor $L_{AS,max}^{13}$ (Basner et al., 2006; Elmenhorst et al., 2012). Further, evidence rated low quality showed an association between road traffic noise and sleep outcomes measured as motility in adults (Frei et al., 2014; Griefahn et al., 2000; Oehrstroem et al., 2006a; Passchier-Vermeer et al., 2007; Pirrera et al., 2014). Finally, there was evidence rated very low quality for an association between road traffic noise and both self-reported and motility-measured sleep disturbance in children (Ising & Ising, 2002; Lercher et al., 2013; Oehrstroem et al., 2006a; Tiesler et al., 2013).

3.1.2.2 Evidence on interventions

This section summarizes the evidence underlying the recommendation on the effectiveness of interventions for road traffic noise exposure. The key question posed was: in the general population exposed to road traffic noise, are interventions effective in reducing exposure to and/or health outcomes from road traffic noise? A summary of the PICOS/PECCOS scheme applied and the main findings is set out in Tables 13 and 14.

Table 13. PICOS/PECCOS scheme of the effectiveness of interventions for exposure to road traffic noise

PICO	Description
Population	General population
Intervention(s)	The interventions can be defined as: (a) a measures that aim to change noise exposure and associated health effects; (b) a measures that aim to change noise exposure, with no particular evaluation of the impact on health; or (c) a measures designed to reduce health effects, but that may not include a reduction in noise exposure.
Comparison	No intervention
Outcome(s)	For average noise exposure: For night noise exposure: 1. cardiovascular disease 1. effects on sleep 2. annoyance 3. cognitive impairment 4. hearing impairment and tinnitus 5. adverse birth outcomes 6. quality of life, well-being and mental health 7. metabolic outcomes

¹³ $L_{AS,max}$ is the maximum time-weighted and A-weighted sound pressure level with SLOW time constant within a stated time interval starting at t1 and ending at t2, expressed in dB.

Table 14. Summary of findings for road traffic noise interventions by health outcome

Type of intervention	Number of participants (studies)	Effect of intervention	Quality of evidence
Annoyance			
Type A – source interventions (change in traffic flow rate, improved road resurfacing, truck restriction strategy, complex set of barriers, road surfaces and other measures)	6096 ^a (9)	- Changes in noise level ranged from around –15 dB to +15.5 dB (various noise metrics). - Most studies found that the intervention resulted in a change in annoyance.	Moderate (downgraded for study limitations; upgraded for dose-response)
Type B – path interventions (dwelling insulation, barrier construction, building intervention)	2970 (7)	- Changes in noise level ranged from –3 dB to –13 dB (various noise metrics). - All studies found that the intervention resulted in a change in annoyance, as estimated by an ERF.	Moderate (downgraded for study limitations; upgraded for dose-response)
Type C – changes in infrastructure (new road tunnel infrastructure)	1211 (2)	- Noise levels reduced by an average of –12 dB ($L_{Aeq,24h}$). - Both studies found lower annoyance responses post intervention, with no change in the controls.	Moderate (downgraded for study limitations; upgraded for dose-response)
Type D – other physical interventions (availability of quiet side to the dwelling, existence of nearby green space)	26 786 (6)	Because of large variability in noise levels between most and least exposed façade (quiet side), access to quiet side and/or green space resulted in less annoyance.	Very low (downgraded for study limitations)
Sleep disturbance			
Type B – path interventions (1: façade insulation; 2: enlargement of motorway lanes but with dwelling insulation, barriers and quiet pavement)	1158 (2)	1: façade insulation resulted in a reduction of 7 dB for indoor noise level. 2: enlargement led to reduction in the extent of population exposure at higher noise levels (55–65 dB) with an increase in lower levels (45–55 dB) - Both path interventions resulted in changes in sleep outcomes	Moderate (downgraded for study limitations)
Type C – changes in infrastructure (new road tunnel infrastructure)	166 (2)	- Noise levels reduced by an average of –12 dB ($L_{Aeq,24h}$). - Both studies found lower sleep disturbance indicators/ improvement in sleep post intervention, with no change in the controls.	Moderate (downgraded for study limitations)
Type D – other physical interventions (availability of quiet side to the dwelling)	100 (1)	An absence of quiet façade resulted in increased reporting of difficulty in falling asleep.	Very low (downgraded for study limitations, inconsistency)
Cardiovascular disease			
Type D – other physical interventions (availability of quiet side to the dwelling)	9203 (4)	Three studies found changes (including in self-reported hypertension) with and without a quiet side. One study found no change.	Very low (downgraded for study limitations)

Note: ^a This figure does not include number of participants from the studies by Langdon & Griffiths (1982) and Baughan & Huddart (1993), as the exact number of respondents was not reported.



Type A – source interventions

Most of the nine source intervention studies – Baughan & Huddart (1993), Brown (1987; 2015), Brown et al. (1985), Griffiths & Raw (1987; 1989), Kastka (1981), Langdon & Griffiths (1982), Pedersen et al. (2013; 2014), Stansfeld et al. (2009b) – showed an effect in annoyance due to changes in road traffic flow rates. In some cases these were combined with other measures like improved road resurfacing, truck restrictions or complex control measures, including barriers or road surfaces. A majority of the changes resulted in reductions of noise levels.

Regarding the strength of association between exposure and annoyance outcome, all intervention studies demonstrated that the response was of at least the magnitude estimated by a steady-state ERF. The limited available evidence on long-term effects shows that this excess response undergoes some attenuation but is largely maintained over several years. In spite of the high risk of bias in all studies, the evidence in the systematic review was initially assessed as high quality, due to an upgrade because of the dose-response effect. However, the GDG decided to downgrade this assessment in an effort to maximize consistency with the grading approach of the remaining systematic reviews. It was therefore rated moderate quality.

Type B – path interventions

Seven path intervention studies – Amundsen et al. (2011; 2013), Bendtsen et al. (2011), Gidloef-Gunnarsson et al. (2010), Kastka et al. (1995), Nilsson & Berglund (2006), Vincent & Champelovier (1993) – explored the effects on annoyance by interventions related to dwelling insulation, barrier constructions and a combination of both, as well as a full-scale building intervention. With the help of pre/post designs, the studies assessed changes in noise exposure achieved by the interventions over different periods of time. In six studies the path intervention was associated with a change in annoyance outcomes. Four of these showed that the annoyance response to the change was in the same direction and of at least the same magnitude estimated by the ERF. In spite of the high risk of bias in all studies, the evidence in the systematic review was initially assessed as high quality, due to an upgrade because of the dose-response effect. However, the GDG decided to downgrade this assessment in an effort to maximize consistency with the grading approach of the remaining systematic reviews. The evidence was therefore rated moderate quality.

Two of the studies (Amundsen et al., 2013; Bendtsen et al., 2011) assessed path interventions and sleep disturbance. The results showed a reduction in the %HSD after the interventions were conducted. One of the studies included a two-year follow-up, revealing the persistence of the effect. Risk of bias was assessed as high in both studies. The evidence was rated moderate quality.

Type C – new/closed infrastructure interventions

Two infrastructural intervention studies (Gidloef-Gunnarsson et al., 2013; Oehrstroem, 2004; Oehrstroem & Skanberg, 2000) evaluated the impact on annoyance of major reductions in road traffic flows, combined with other environmental improvements. One was a new road tunnel infrastructure, resulting in substantial traffic and noise levels reductions for residents near the previously heavy-traffic road. Both studies were pre/post designs using repeated measures of annoyance outcomes. Following the reduction in noise levels (around -12 dB $L_{Aeq,24h}$), both studies demonstrated a statistically significant lower degree of annoyance, while there was no change in

the control group. Both also reported that the after-scores in the studies matched those estimated by the ERF, but both reported excess response, meaning that the response to change was in the direction estimated by the ERF but much steeper. In spite of the high risk of bias in all studies, the quality of the evidence in the systematic review was initially assessed as high, due to an upgrade because of the dose-response effect. However, the GDG decided to downgrade this assessment in an effort to maximize consistency with the grading approach of the remaining systematic reviews. The evidence was therefore rated moderate quality.

Two studies investigated the impact of new tunnels that removed traffic flow from surface roads on sleep disturbance (Oehrstroem, 2004; Oehrstroem & Skanberg, 2000; 2004). Subjective and objective measures of sleep quality were assessed before and after the intervention. Both studies demonstrated a statistically significant lower reporting of various sleep disturbance indicators post intervention. One study reported statistically significantly reduced time spent in bed after the intervention, which, according to the authors, could suggest increased sleep efficiency. Risk of bias was assessed as high, so this evidence was rated moderate quality.



Type D – other physical infrastructure interventions

No intervention studies were available to assess impacts on annoyance of other physical interventions. The only relevant studies (Babisch et al., 2012; de Kluizenaar et al, 2011; 2013; Gidloef-Gunnarsson & Oehrstroem 2007; van Renterghem & Botteldooren, 2012; 2010) did not provide direct evidence of an intervention. Instead, they provided indirect evidence on the magnitude of the likely effect of certain interventions (e.g. using the quiet side of the dwelling, green space in the neighbourhood) by comparing responses from groups with and without the intervention/feature of interest. All studies found an effect of the presence of the dimension investigated; in all but one, the effect was statistically significant. Risk of bias was assessed as high in all studies, so the evidence was rated very low quality.

One study investigated a subjective assessment of difficulty in falling asleep (van Renterghem & Botteldooren, 2012), before and after the intervention. The difference in the proportion of participants reporting difficulty falling asleep “at least sometimes” between homes with and without a quiet side was statistically significant. Absence of a quiet façade resulted in increased reporting of this sleep parameter. Confounding was adjusted for in the analyses of the ERFs, including noise sensitivity, window-closing behaviour and front-façade L_{den} . Risk of bias was assessed as high, so the evidence was rated very low quality.

Four studies that assessed the effect of other physical interventions on cardiovascular disease were identified (Babisch et al., 2012; 2014a; Bluhm et al., 2007; Lercher et al., 2011). Three of these found changes, including self-reported hypertension, with and without a quiet side of the dwelling; in two the difference was statistically significant. The risk of bias in these studies was generally high, so the evidence was rated very low quality.

3.1.2.3 Consideration of additional contextual factors

As the foregoing overview has shown, ample evidence about the adverse health effects of long-term exposure to road traffic noise exists. Based on the quality of the available evidence, the GDG set the strength of the recommendation on road traffic noise at strong. As a second step, it qualitatively

assessed contextual factors to explore whether other considerations could have a relevant impact on the recommendation strength. These considerations mainly concerned the balance of harms and benefits, values and preferences, equity, and resource use and implementation.

When assessing the balance of harms and benefits of interventions to reduce exposure to road traffic noise, the GDG initially noted that road traffic is the most widespread source of noise pollution, measured in terms of the number of affected people both within and outside urban areas. The EEA estimates that more than 100 million people in Europe are exposed to L_{den} levels above 55 dB; for night-time road traffic noise, over 72 million Europeans are exposed to L_{night} levels above 50 dB (Blanes et al., 2017).¹⁴ The amount of road traffic noise emitted is unlikely to decrease significantly: both transport demand, including for passenger cars (EC, 2016b), and the number of city inhabitants (Eurostat, 2016) are expected to increase. Considering the significant burden of disease attributable to exposure to road traffic noise (WHO Regional Office for Europe & JRC, 2011), the GDG expects substantial health benefits to evolve from implementing the recommendations to reduce population exposure to road traffic noise. Depending on the intervention measures used (such as restrictions of traffic), possible harms could include effects on the transportation of goods and on individual mobility of the population. Both can have impacts on local, national and international economies. Overall, the GDG estimated that the benefits gained from minimizing adverse health effects due to road traffic noise exposure outweigh the possible (economic) harms.

Considering values and preferences, it has been established that people appreciate quiet areas as beneficial for their health and well-being, especially in urban areas (Shepherd et al., 2013; Gidloef-Gunnarsson & Oehrstroem, 2007; Oehrstroem et al., 2006b). Nevertheless, the GDG recognized that the convenience of individual mobility with the help of passenger cars is valued overall by large parts of the population in the EU, as illustrated by the sustained high volume of passenger kilometres driven in Europe (EEA, 2016a; 2017a). In general, values and preferences are expected to vary throughout society, as exposure to environmental noise and continuous road traffic noise is not equally distributed: those of individuals directly affected by long-term road traffic exposure are likely to differ from those that are not affected. Individuals with a higher average sound pressure level of road traffic noise are, for example, more willing to pay to reduce their noise exposure (Bristow et al., 2014).

In light of the dimension of equity, the GDG highlighted the fact that the risk of exposure to road traffic noise is not equally distributed throughout society. People with lower socioeconomic status and other disadvantaged groups often live in more polluted and louder areas, including in proximity to busy roads (EC, 2016a). Moreover, socioeconomic factors are not only related to differences in exposure to environmental factors such as noise but are also associated with increased vulnerability and poorer coping capacities (Karpati et al., 2002).

With resource use and implementation considerations, the GDG recognized that no comprehensive cost–benefit analysis for the WHO European Region yet exists, so this assessment is based on informed expert judgement regarding the feasibility of implementing the recommendation for the majority of the population. As the systematic review of environmental noise interventions and their

¹⁴ These are gap-filled figures based on the reported data and including the situation both within and outside cities, as defined by the END.

associated impact on health shows, various effective measures exist to reduce noise exposure from road traffic and improve health (Brown & van Kamp, 2017). The resources needed to implement these measures vary as they rely on the type of intervention and the context. The GDG pointed out the following four major solutions, which are known to be cost-effective: choice of appropriate tyres, use of low-noise road surfaces, building of noise barriers and installation of soundproof windows (CSES et al., 2016). Other types of intervention include limitations of speed or type of traffic allowed on roads.

Regarding feasibility of implementation, the GDG was convinced that many of the solutions can be planned as part of regular maintenance processes and accelerated fleet and road modernization. In particular, appropriate tyres and road surfaces are only slightly more expensive than existing products, and various countries have already considered or adopted similar interventions to reduce noise levels (Ohiduzzaman et al., 2016; Sirin, 2016). This indicates that solutions to achieve recommended noise levels can be implemented and carry a reasonable cost on a societal level. The GDG noted, however, that the feasibility of implementing measures can be hindered by the fact that costs and benefits are not evenly distributed. In most cases, the health benefits gained by interventions that reduce long-term road traffic exposure accrue to citizens, whereas the costs are borne by road users, private companies and public authorities. Furthermore, the GDG expects challenges in the implementation of all long-term measures that include changes in behaviour of the population, such as increased use of car-sharing or public transport. Even though the overall costs are expected to be significant, because of the large number of people affected, the benefit of implementation of the recommendation to minimize the risk of adverse health effects due to road traffic noise for a majority of the population exceeds the resources needed.

In light of the assessment of the contextual factors in addition to the quality of evidence, the recommendation remains strong.

Other nonpriority adverse health outcomes

As an additional consideration, although not priority health outcomes and coming from a single study, the GDG noted the evidence rated moderate quality for an association between road traffic noise and the prevalence of diabetes (van Kempen et al., 2018). The noise levels in the study identified ranged from around 50 dB to 70 dB L_{den} , so the recommendation proposed is thought to be protective enough for this health outcome. Thus, it did not lead to a change in the recommendation.

Additional considerations or uncertainties

Individual noise annoyance judgements of residents are to a large extent moderated by personal variables (such as noise sensitivity and coping capacity). However, further situational factors that apply to many residents should be taken into account when analysing noise annoyance from road traffic noise, as they may moderate the relationship. These include the type(s) of road being considered (highways, urban main roads, secondary roads and so on) and the related traffic composition (share of cars, motorcycles and heavy and loud trucks) and pattern (fluctuation, frequency, intermittency). Moreover, the location of settlements and/or individual dwellings, proximity to the road, and location and availability of a quiet façade can also influence the relationship when predicting health outcomes such as annoyance.



3.1.3 Summary of the assessment of the strength of the recommendations

Table 15 provides a comprehensive summary of the different dimensions for the assessment of the strength of the road traffic noise recommendations.

Table 15. Summary of the assessment of the strength of the road traffic noise recommendation

Factors influencing the strength of recommendation	Decision
Quality of evidence	Average exposure (L_{den}) <i>Health effects</i> • Evidence for a relevant RR increase for incidence of IHD at 59 dB L_{den} was rated high quality. • Evidence for the incidence of hypertension was rated low quality. • Evidence for a relevant absolute risk of annoyance at 53 dB L_{den} was rated moderate quality. • Evidence for a relevant RR increase for reading and oral comprehension was rated very low quality. <i>Interventions</i> • Evidence on effectiveness of interventions to reduce noise exposure and/or health outcomes from road traffic noise is of varying quality. Night-time exposure (L_{night}) <i>Health effects</i> • Evidence for a relevant absolute risk of sleep disturbance related to night noise exposure from road traffic at 45 dB L_{night} was rated moderate quality. <i>Interventions</i> • Evidence on effectiveness of interventions to reduce noise exposure and/or sleep disturbance from road traffic noise is of varying quality.
Balance of benefits versus harms and burdens	Health benefits can be gained from markedly reducing exposure of the population to road traffic noise; benefits outweigh the harms of interventions to reduce continuous road traffic noise.
Values and preferences	Quiet areas are valued by the population, especially by those affected by continuous noise exposure. Some variability is possible between those who benefit from interventions to reduce road traffic noise and those who finance the interventions.
Equity	Risk of exposure to road traffic noise is not equally distributed.
Resource use and implications	No comprehensive cost-effectiveness analysis data are available; nevertheless, a wide range of solutions exists and several are being implemented, showing that effective interventions are both feasible and economically reasonable.
Decisions on recommendation strength	• Strong for guideline level for average noise exposure (L_{den}) • Strong for guideline value for average night noise exposure (L_{night}) • Strong for specific interventions to reduce noise exposure



3.2 Railway noise

Recommendations

For average noise exposure, the GDG **strongly** recommends reducing noise levels produced by railway traffic below **54 dB L_{den}** , as railway noise above this level is associated with adverse health effects.

For night noise exposure, the GDG **strongly** recommends reducing noise levels produced by railway traffic during night time below **44 dB L_{night}** , as railway noise above this level is associated with adverse effects on sleep.

To reduce health effects, the GDG **strongly** recommends that policy-makers implement suitable measures to reduce noise exposure from railways in the population exposed to levels above the guideline values for average and night noise exposure. There is, however, insufficient evidence to recommend one type of intervention over another.



3.2.1 Rationale for the guideline levels for railway noise

The exposure levels were derived in accordance with the prioritizing process of critical health outcomes described in section 2.4.3. For each of the outcomes, the exposure level was identified by applying the benchmark, set as relevant risk increase to the corresponding ERF. In the case of exposure to railway noise, the process can be summarized as follows (Table 16).

Table 16. Average exposure levels (L_{den}) for priority health outcomes from railway noise

Summary of priority health outcome evidence	Benchmark level	Evidence quality
Incidence of IHD No studies were available and therefore incidence of IHD could not be used to assess the exposure level.	5% increase of RR	No studies met the inclusion criteria/no studies available
Incidence of hypertension One study met the inclusion criteria. There was no significant increase of risk associated with increased noise exposure in this study.	10% increase of RR	Low quality
Prevalence of highly annoyed population There was an absolute risk of 10% at a noise exposure level of 53.7 dB L_{den} .	10% absolute risk	Moderate quality
Permanent hearing impairment	No increase	No studies met the inclusion criteria/no studies available
Reading skills and oral comprehension in children	One-month delay	No studies met the inclusion criteria/no studies available

In accordance with the prioritization process (see section 2.4.3), the GDG set a guideline exposure level of 53.7 dB L_{den} for average exposure, based on the relevant increase of the absolute %HA. In accordance with the defined rounding procedure, the value was rounded to 54 dB L_{den} . As the evidence on the adverse effects of railway noise was rated moderate quality, the GDG made the recommendation strong.

Next, the GDG assessed the evidence for night noise exposure and its effect on sleep disturbance (Table 17).

Table 17. Night-time exposure levels (L_{night}) for priority health outcomes from railway noise

Summary of priority health outcome evidence	Benchmark level	Evidence quality
Sleep disturbance 3% of the participants in studies were highly sleep-disturbed at a noise level of 43.7 dB L_{night}	3% absolute risk	Moderate quality

Based on the evidence of the adverse effects of railway noise on sleep disturbance, the GDG defined a guideline exposure level of 43.7 dB L_{night} . The exact exposure value was rounded to 44 dB L_{night} . As the evidence was rated moderate quality, the GDG made the recommendation strong.

The GDG also considered the evidence for the effectiveness of interventions. The results showed that:

- intervening at the source by applying rail grinding procedures can reduce noise annoyance;
- behavioural interventions such as informing the community about noise interventions can reduce noise annoyance.

In light of the strong evidence about the adverse health effects, the GDG followed a precautionary approach and made a strong recommendation for interventions on railway noise, as it was confident that interventions are realizable and that best practices already exist for the management of noise from railways. Since the empirical evidence on the effectiveness of different types of intervention was rated either low or very low quality, the GDG felt that no recommendation could be made on the preferred type of intervention, and agreed not to recommend any specific type of intervention over another.

3.2.1.1 Other factors influencing the strength of recommendations

Other factors considered in the context of recommendations on railway noise included those related to values and preferences, benefits and harms, resource implications, equity, acceptability and feasibility; moreover, nonpriority health outcomes were considered. The assessment of all these factors – especially the values and preferences involved in railway noise – did not lead to a change in the strength of the recommendations. Further details are provided in Section 3.2.2.3.

3.2.2 Detailed overview of the evidence

The following sections provide a detailed overview of the evidence constituting the basis for setting the recommendations on railway noise. It is presented and summarized separately for each of the critical health outcomes, and the GDG’s judgement of the quality of evidence is indicated (for a detailed overview of the evidence on important health outcomes, see Annex 4). Research into health outcomes and effectiveness of interventions is addressed consecutively.

A comprehensive summary of all evidence considered for each of the critical and important health outcomes can be found in the eight systematic reviews published in the *International Journal of Environmental Research and Public Health* (see section 2.3.2 and Annex 2).

3.2.2.1 Evidence on health outcomes

The key question posed was: in the general population exposed to railway noise, what is the exposure–response relationship between exposure to railway noise (reported as various noise indicators) and the proportion of people with a validated measure of health outcome, when adjusted for main confounders? A summary of the PICOS/PECCOS scheme applied and the main findings is set out in Tables 18 and 19.

Table 18. PICOS/PECCOS scheme of critical health outcomes for exposure to railway noise

PECO	Description
Population	General population
Exposure	Exposure to high levels of noise produced by railway traffic (average/night time)
Comparison	Exposure to lower levels of noise produced by railway traffic (average/night time)
Outcome(s)	For average noise exposure: 1. cardiovascular disease 2. annoyance 3. cognitive impairment 4. hearing impairment and tinnitus 5. adverse birth outcomes 6. quality of life, well-being and mental health 7. metabolic outcomes For night noise exposure: 1. effects on sleep

Table 19. Summary of findings for health effects from exposure to railway noise (L_{den})

Noise metric	Priority health outcome measure	Quantitative risk for adverse health	Lowest level of exposure across studies	Number of participants (studies) ^a	Quality of evidence
Cardiovascular disease					
L_{den}	Incidence of IHD	–	–	–	–
L_{den}	Incidence of hypertension	RR = 0.96 (95% CI: 0.88–1.04) per 10 dB increase	N/A	7249 (1)	Low (downgraded for risk of bias and availability of only one study)
Annoyance					
L_{den}	%HA	OR = 3.53 (95% CI: 2.83–4.39) per 10 dB increase	34	10 970 (10)	Moderate (downgraded for inconsistency, directness; upgraded for dose-response)
Cognitive impairment					
L_{den}	Reading and oral comprehension	–	–	–	–
Hearing impairment and tinnitus					
L_{den}	Permanent hearing impairment	–	–	–	–

Note: ^a Results are partly derived from population-based studies.

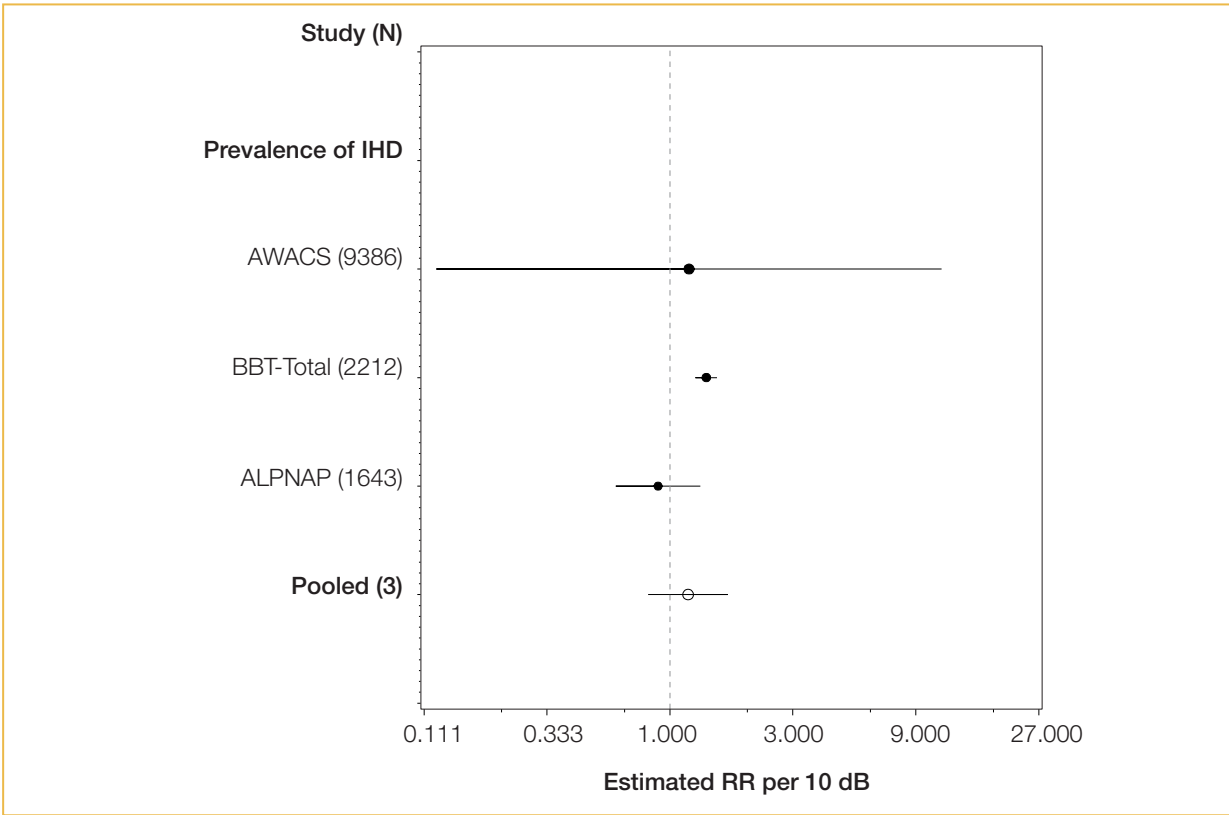


Cardiovascular disease

IHD

No evidence was available on the relationship between railway noise and the incidence of or mortality from IHD. Four cross-sectional studies were identified, however, that assessed the prevalence of IHD in a total of 13 241 participants, including 283 cases (Heimann et al., 2007; Lercher et al., 2008; 2011; van Poll et al., 2014). The overall risk was not statistically significantly increased: the RR was 1.18 (95% CI: 0.82–1.68) per 10 dB L_{den} increase, with inconsistency across studies (see Fig. 7). The evidence was rated very low quality.

Fig. 7. The association between exposure to railway noise (L_{den}) and prevalence of IHD



Notes: The dotted vertical line corresponds to no effect of exposure to railway noise. The black circles correspond to the estimated RR per 10 dB and 95% CI. The white circle represents the pooled random effect estimates and 95% CI. For further details on the studies included in the figure please refer to the systematic review on environmental noise and cardiovascular and metabolic effects (van Kempen et al., 2018).

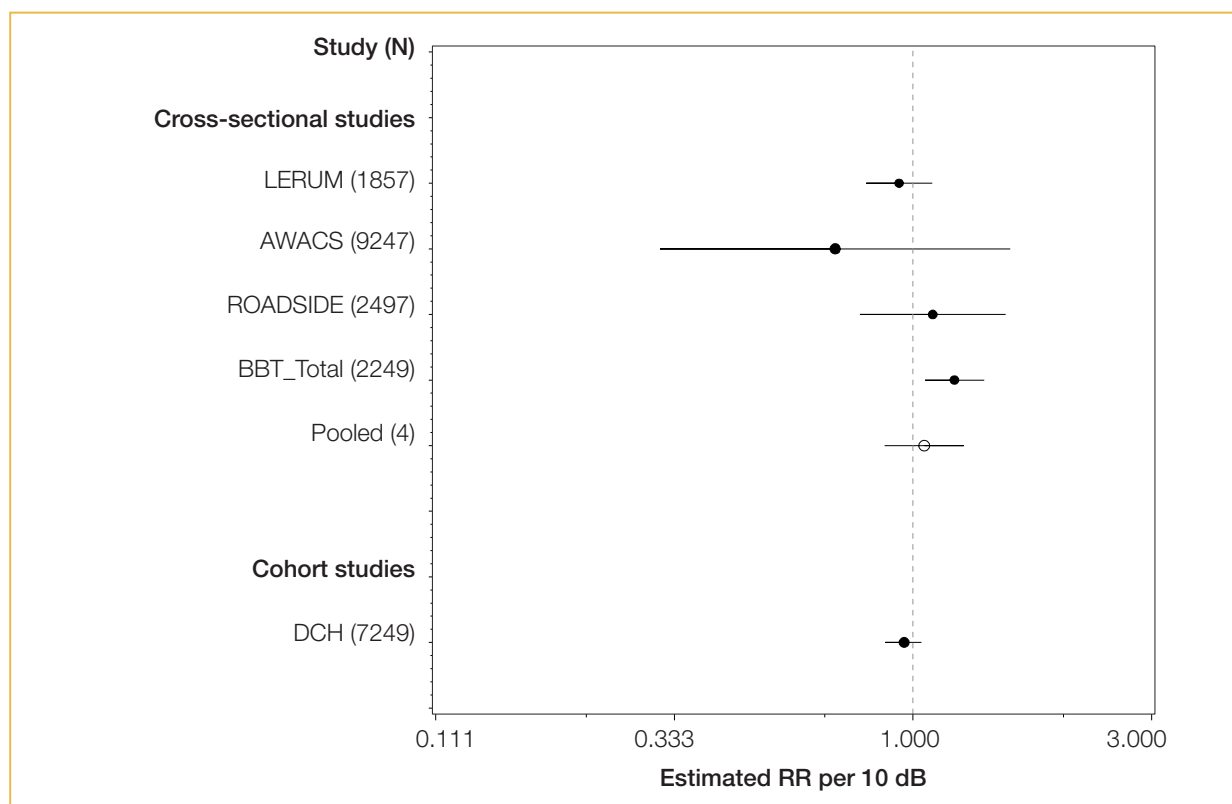
Hypertension

One cohort study on the relationship between railway noise and hypertension was identified; it assessed the incidence among people living in Denmark (Sørensen et al., 2011; 2012a). The study involved 7249 participants, including 3145 cases. The authors did not find an association between railway noise exposure and incidence of hypertension, with RR = 0.96 (95% CI: 0.88–1.04) per 10 dB L_{den} increase. This evidence was rated low quality.

In addition, five cross-sectional studies assessed the prevalence of hypertension in 15 850 participants, including 2059 cases (Barregard et al., 2009; Eriksson et al., 2012; Lercher et al., 2008; 2011; van Poll et al., 2014). The overall RR increase was not statistically significant, at 1.05 (95% CI: 0.88–1.26) per 10 dB L_{den} increase. Moreover, there was inconsistency among the results across studies. The evidence was rated very low quality.

Fig. 8 presents the studies investigating the relationship between railway noise and different measures of hypertension.

Fig. 8. The association between exposure to railway noise (L_{den}) and hypertension



Notes: The dotted vertical line corresponds to no effect of exposure to railway noise. The black dots correspond to the estimated RR per 10 dB and 95% CI. The white circle represents the summary estimate and 95% CI.

For further details on the studies included in the figure please refer to the systematic review on environmental noise and cardiovascular and metabolic effects (van Kempen et al., 2018).

Stroke

As for IHD, no evidence was available on the relationship between railway noise and incidence of or mortality from stroke. However, one cross-sectional study was identified that assessed the prevalence of stroke in 9365 participants, including 89 cases (van Poll et al., 2014). The overall risk was not statistically significantly increased, with RR = 1.07 (95% CI: 0.92–1.25) per 10 dB L_{den} increase. The evidence was rated very low quality.

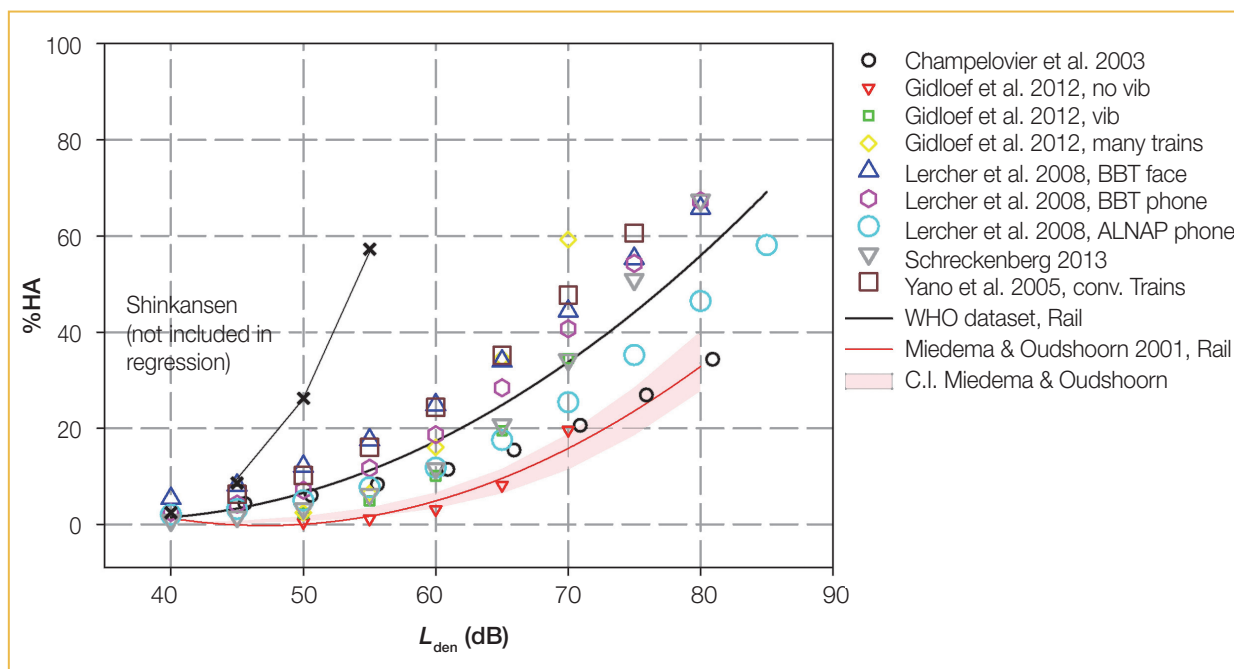
Children's blood pressure

No evidence was available for the association between railway noise and the systolic and/or diastolic blood pressure of children in residential and/or educational settings.

Annoyance

In total, 10 studies with ERFs on the association between railway noise and annoyance were included in analyses (Champelovier et al., 2003; Gidloef-Gunnarsson et al., 2012; Lercher et al., 2007; 2008; Sato et al., 2004; Schreckenberg, 2013; Yano et al., 2005; Yokoshima et al., 2008). The studies incorporated individual data from 10 970 participants. The estimated data points of each of these studies are plotted in Fig. 9, alongside an aggregated ERF including the data from all the individual studies (see the black line for “WHO dataset, Rail”). The lowest category of noise exposure considered in any of the studies, and hence included in the systematic review is 40 dB, corresponding to approximately 1.5%HA. The 10% benchmark for %HA is reached at 53.7 dB L_{den} (see Fig. 9).

Fig. 9. Scatterplot and quadratic regression of the relationship between railway noise (L_{den}) and annoyance (%HA)



Notes: The ERF by Miedema & Oudshoorn (2001) is added in red for comparison.

There is no indication of 95% CIs of the WHO dataset curve, as a weighting based on the total number of participants for each 5 dB L_{den} sound class could not be calculated; weighting based on all participants of all sound classes proved to be unsuitable. The range of data included is illustrated by the distribution of data points.

For further details on the studies included in the figure please refer to the systematic review on environmental noise and annoyance (Guski et al., 2017).

Table 20 shows the %HA for railway noise exposure. The calculations are based on the regression equation $\%HA = 38.1596 - 2.05538 \times L_{den} + 0.0285 \times L_{den}^2$ derived from the systematic review (Guski et al., 2017). The overall evidence was rated moderate quality. Additional statistical analyses of annoyance outcomes supported these findings. When comparing railway noise exposure at 50 dB and 60 dB, the analyses revealed evidence rated moderate quality for an association between railway noise and %HA for an increase per 10 dB (OR = 3.40; 95% CI: 2.05–5.62). Moreover, evidence rated high quality was available for the increase in %HA per 10 dB increase in sound exposure, when data on all sound classes were included (OR = 3.53; 95% CI: 2.83–4.39).

Table 20. The association between exposure to railway noise (L_{den}) and annoyance (%HA)

L_{den} (dB)	%HA
40	1.5
45	3.4
50	6.6
55	11.3
60	17.4
65	25.0
70	33.9
75	44.3
80	56.1



Cognitive impairment

Studies of railway noise on children's reading and oral comprehension were lacking. Nevertheless, other measures of cognition yielded evidence rated very low quality for an association between railway noise and children with poorer performance on standardized assessment tests (Bronzaft, 1981; Bronzaft & McCarthy, 1975). Evidence for the association between railway noise and children having poorer long-term memory (Lercher et al., 2003) was rated very low quality. No studies examined effects on short-term memory.

There was no clear relation between railway noise and attention in children (Lercher et al., 2003), and this evidence was rated very low quality.

Hearing impairment and tinnitus

No studies were found, and therefore no evidence was available on the association between railway noise and hearing impairment and tinnitus.

Sleep disturbance

For railway noise and self-reported sleep outcomes (awakenings from sleep, the process of falling asleep and sleep disturbance), five studies were identified that included a total of 7133 participants (Bodin et al., 2015; Hong et al., 2010; Sato et al., 2004; Schreckenber, 2013). The studies were cross-sectional and conducted on healthy adults. The health outcome was measured by self-reporting via general health surveys and noise surveys that included questions about sleep in general, and other questions about how noise affects sleep (Table 21).

Table 21. Summary of findings for health effects from exposure to railway noise (L_{night})

Noise metric	Priority health outcome measure	Quantitative risk for adverse health	Lowest level of exposure across studies	Number of participants (studies)	Quality of evidence
Effects on sleep					
L_{night}	%HSD	OR: 3.06 (95% CI: 2.38–3.93) per 10 dB increase	33 dB	7133 (5)	Moderate (downgraded for study limitations, inconsistency; upgraded for dose-response, magnitude of effect)

The model in the systematic review (Basner & McGuire, 2018) was based on outdoor L_{night} levels between 40 dB and 65 dB only; 40 dB was chosen as the lower limit because of possible inaccuracies in predicting lower noise levels. The range of noise exposure reported in the studies was 27.5–82.5 dB L_{night} . About 2% (95% CI: 0.79–3.48) of the population was characterized as highly sleep-disturbed for L_{night} levels of 40 dB. The %HSD at other, higher levels of railway noise is presented in Table 17. The association between railway noise and the probability of being sleep-disturbed was OR: 3.1 (95% CI: 2.4–3.9) per 10 dB increase in noise. This evidence was rated moderate quality.

Table 22. The association between exposure to railway noise (L_{night}) and sleep disturbance (%HSD)

L_{night} (dB)	%HSD	95% CI
40	2.1	0.79–3.48
45	3.7	1.63–5.71
50	6.3	3.12–9.37
55	10.4	5.61–15.26
60	17.0	9.48–24.37
65	26.3	15.20–37.33

Additional analyses were conducted for sleep quality measures, which provided supporting evidence on the overall relationship between railway noise and sleep. When the noise source was not specified in the question, the relationship between railway noise and self-reported sleep outcomes was still positive but no longer statistically significant, with an OR of 1.27 (95% CI: 0.89–1.81) per 10 dB increase (Bodin et al., 2015; Brink, 2011; Frei et al., 2014). This evidence was rated very low quality.

There was evidence rated moderate quality for an association between railway noise and the probability of additional awakenings, measured with polysomnography, with an OR of 1.35 (95% CI: 1.21–1.52) per 10 dB increase in indoor $L_{\text{AS,max}}$ (Elmenhorst et al., 2012). Finally, evidence rated low quality was available for an association between railway noise and sleep outcomes measured as motility in adults (Griefahn et al., 2000; Hong et al., 2006; Lercher et al., 2010; Passchier-Vermeer et al., 2007), and rated very low quality for an association between railway noise and both self-reported and motility-measured sleep disturbance in children (Ising & Ising, 2002; Lercher et al., 2013; Tiesler et al., 2013).

3.2.2.2 Evidence on interventions

This section summarizes the evidence underlying the recommendation on the effectiveness of interventions for railway noise exposure (Tables 23 and 24). The key question posed was: in the

general population exposed to railway noise, are interventions effective in reducing exposure to and/or health outcomes from railway noise? A summary of the PICOS/PECCOS scheme applied and the main findings is set out in Tables 23 and 24.

Table 23. PICOS/PECCOS scheme of the effectiveness of interventions for exposure to railway noise

PICO	Description
Population	General population
Intervention(s)	The interventions can be defined as: (a) a measure that aims to change noise exposure and associated health effects; (b) a measure that aims to change noise exposure, with no particular evaluation of the impact on health; or (c) a measure designed to reduce health effects, but that may not include a reduction in noise exposure.
Comparison	No intervention
Outcome(s)	For average noise exposure: 1. cardiovascular disease 2. annoyance 3. cognitive impairment 4. hearing impairment and tinnitus 5. adverse birth outcomes 6. quality of life, well-being and mental health 7. metabolic outcomes For night noise exposure: 1. effects on sleep



Table 24. Summary of findings for railway noise interventions by health outcome

Type of intervention	Number of participants (studies)	Effect of intervention	Quality of evidence
Annoyance			
Type A – source interventions (rail grinding)	81 (1)	- Changes in noise level as a consequence of the intervention ranged from around –7dB to –8 dB. - Most studies found changes in annoyance outcomes, persisting more than 12 months after the intervention.	Very low (downgraded for study limitations, inconsistency, imprecision)
Type C – changes in infrastructure (new rail infrastructure)	6000 ^a (1)	- A very small increase in total noise exposure was found (most had <+1 dB change; some had +2–4 dB change). - Original noise from road traffic overwhelmed the train noise for effectively all participants.	Very low (downgraded for study limitations, inconsistency, imprecision)
Type E – behaviour change interventions (informing the community about a noise intervention)	411 (1)	- Exposure levels were not reported; emission levels reduced by 1–2 dB. - A reduction in annoyance of the community as a result of the intervention was reported.	Very low (downgraded for study limitations, inconsistency, imprecision)

Note: ^a According to Lam & Au (2008), this records the number of invitation letters sent; the response rate was not reported.

Three studies on railway noise interventions met the criteria to be included in the evidence base. All studies consisted of a pre/post design and reported annoyance outcomes at people's dwellings (Lam & Au, 2008; Moehler et al., 1997; Schreckenberg et al., 2013). They could be categorized as a source intervention, a new/closed infrastructure intervention and a communication intervention. In two of the studies, the changes in exposure after the intervention were only small, although there were significant effects on noise annoyance. The study on source interventions and annoyance revealed that a change of -10 dB in noise exposure led to a significant reduction in annoyance, which persisted over a period of 12 months after the intervention. As confounding was not addressed, and railway noise was not the dominant sound source in the studies, the evidence was rated very low quality.

3.2.2.3 Consideration of additional contextual factors

As the foregoing overview has shown, sufficient evidence about the adverse health effects of long-term exposure to railway noise exists. Based on the quality of the available evidence, the GDG set the strength of recommendation on railway noise at strong. As a second step, it qualitatively assessed contextual factors to explore whether other considerations could have a relevant impact on the recommendation strength. These contextual considerations mainly concerned the balance of harms and benefits, values and preferences, and resource use and implementation.

When assessing the balance of harms and benefits of interventions to reduce exposure to railway noise and minimize noise-associated adverse health effects, the GDG recognized that railway transportation is the second most dominant source of environmental noise in Europe. Based on EEA estimates, the number of people exposed to L_{den} above 55 dB and L_{night} above 50 dB from railway noise is 17 million and 15 million, respectively (Blanes et al., 2017).¹⁵ In light of the burden of disease from environmental noise, and railway noise in particular, the GDG agreed that the health benefits from a reduction of long-term railway noise exposure (especially during night time) to the recommended values would be significant. Considering possible harms related to adaptation of the recommended values, the GDG noted that reliance on railway transportation has increased in recent years in Europe and is expected to increase further, as an important component of the shift towards a greener economy. At a societal level, an environmental and economic benefit from the use of rail transportation is expected: trains contribute to lower environmental pollution and carbon emission than road transportation. Therefore, there is a need to balance the expected health benefits from reduced continuous railway noise exposure and the overall positive effects on the health of the population from increased reliance on the comparatively environmentally friendly mode of railway transportation. Overall, the GDG agreed that even though fewer people are exposed to railway noise than road traffic noise, it remains a major source of localized noise pollution; therefore, considerable benefits are gained by reducing exposure to railway noise.

When exploring values and preferences, the GDG acknowledged that, in general, people value rail as an alternative and more sustainable transportation method than air or road traffic (EEA, 2016a; 2016b; 2017b). Furthermore, the values and preferences in relation to implementation of the recommendation are expected to vary: those of individuals living in the vicinity of railway tracks are expected to differ from those of the rest of the population not exposed to railway noise on a long-term basis. Economic depreciation of housing and fear of adverse health effects were assumed

¹⁵ These are gap-filled figures based on the reported data and including the situation both within and outside cities, as defined by the END.

to be two main aspects influencing the evaluation of affected individuals. This especially applies to areas where new railway tracks are being built, as this results in considerable change for local inhabitants. Moreover, the GDG acknowledged that preferences might also vary in the policy-making domain across different countries as the implementation of the recommendations would mean a renunciation of the so-called “railway bonus”.¹⁶

On resource use and implementation considerations, the GDG pointed out that no comprehensive cost-benefit analysis for the WHO European Region has yet been conducted, so this assessment is based on informed qualitative expert judgement regarding the feasibility of implementing the recommendation for the majority of the population. The systematic review of environmental noise interventions and their associated impact on health shows that various measures to reduce continuous noise from railway traffic exist, although knowledge about their effectiveness remains limited (Brown & van Kamp, 2017). The GDG noted that the resources needed to implement different measures may vary considerably, as they depend on the situation and the type of intervention required. Implementation of some measures is expected to be most feasible during the development of new railway tracks; such as rail pads, bi-bloc sleepers, small noise barriers and – in extreme cases – tunnels, cuttings or earthwork barriers. Other interventions include acoustic rail grinding, noise barriers built alongside the tracks, construction of quieter locomotives and wagons and replacement of brakes on freight trains. The GDG assumed that most of these solutions could be planned as part of regular maintenance or, for instance, by speeding up fleet modernization and track modernization. Even though not broadly implemented, the solutions mentioned above have already been considered or adopted to reduce noise levels from railway noise exposure. Some EU countries (such as Germany), have programmes to replace old brake blocks from freight trains with newer, quieter ones and to ban all freight trains with old brake blocks from 2020 (Umweltbundesamt, 2017). This illustrates that solutions to achieve recommended noise levels can be implemented at a reasonable cost. Overall, the GDG agreed that the benefit of implementation of the recommendation to minimize the risk of adverse health effects due to railway noise for a majority of the population exceeds the (monetary) resources needed.



In light of the assessment of the contextual factors in addition to the quality of evidence, the recommendation remains strong.

Additional considerations or uncertainties

The GDG acknowledged that the main body of evidence for the recommendations on railway noise for average exposure was based on annoyance studies, conducted mainly in Asia and Europe. Studies are few for other priority health outcomes, and the evidence was generally rated low/very low quality. There is therefore uncertainty about the effects on health outcomes. Nevertheless, as a precautionary approach, a strong recommendation is made for average exposure to L_{den} , as a broad evidence base exists for health effects from exposure to other sources of transportation noise. However, the GDG stressed the importance of further research into health effects due to long-term exposure to railway noise.

Moreover, situational factors should be taken into account when analysing annoyance from railway noise. In particular, ground-borne vibrations are sometimes an additional exposure variable in railway

¹⁶ The “railway bonus” is a correction factor commonly applied in the noise abatement policy domain in recent decades. It subsidizes the noise rating level for railway transportation by a predefined factor (Schuemer & Schuemer-Kohrs, 1991).

noise situations – especially in the case of annoyance – which may be difficult to separate from noise effects. In the set of 11 studies included in the systematic review on railway noise and annoyance, only two explicitly mentioned ground-borne vibrations as an additional source of annoyance.

Overall, the low-carbon, low-polluting nature of railway transport, especially using electric trains, means that rail is favoured over road and air traffic. However, night-time railway traffic on busy lines, including freight traffic, can be a significant source of sleep disturbance. Thus, guideline values should be set to encourage the development of rail traffic in Europe while at the same time giving adequate protection to residents from sleep disturbance.

3.2.3 Summary of the assessment of the strength of the recommendations

Table 25 provides a comprehensive summary of the different dimensions for the assessment of the strength of the railway noise recommendations.

Table 25. Summary of the assessment of the strength of the recommendation

Factors influencing the strength of recommendation	Decision
Quality of evidence	Average exposure (L_{den}) <i>Health effects</i> - Evidence for a relevant absolute risk of annoyance at 54 dB L_{den} was rated moderate quality. - Evidence for a relevant RR increase of the incidence of hypertension was rated low quality. One study met the inclusion criteria but did not find a significant increase. <i>Interventions</i> - Evidence that different types of intervention reduce noise annoyance from railways was rated very low quality. Night-time exposure (L_{night}) <i>Health effects</i> - Evidence for a relevant absolute risk of sleep disturbance related to night noise exposure from railways at 44 dB L_{night} was rated moderate quality. <i>Interventions</i> - No evidence was available on the effectiveness of interventions to reduce noise exposure and/or sleep disturbance from railway noise.
Balance of benefits versus harms and burdens	Railway noise is a major source of localized pollution. The health benefits of adapting the recommendation outweigh the harms. Nevertheless, it is important to consider the relevance of railways as an environmentally friendly mode of transportation.
Values and preferences	Quiet areas are valued by the population; especially by those affected by continuous noise exposure. Some variability is expected among those directly affected by railway noise and those not affected.
Resource implications	No comprehensive cost-effectiveness-analysis data are available, although a wide range of interventions exists, indicating that measures are both feasible and economically reasonable.
Decisions on recommendation strength	Strong for guideline value for average noise exposure (L_{den}). Strong for guideline value for night noise exposure (L_{night}). Strong for specific interventions to reduce noise exposure.



3.3 Aircraft noise

Recommendations

For average noise exposure, the GDG **strongly** recommends reducing noise levels produced by aircraft below **45 dB L_{den}** , as aircraft noise above this level is associated with adverse health effects.

For night noise exposure, the GDG **strongly** recommends reducing noise levels produced by aircraft during night time below **40 dB L_{night}** , as aircraft noise above this level is associated with adverse effects on sleep.

To reduce health effects, the GDG strongly recommends that policy-makers implement suitable measures to reduce noise exposure from aircraft in the population exposed to levels above the guideline values for average and night noise exposure. For specific interventions the GDG recommends implementing suitable changes in infrastructure.



3.3.1 Rationale for the guideline levels for aircraft noise

The exposure levels were derived in accordance with the prioritization process of critical health outcomes described in section 2.4.3. For each of the outcomes, the exposure level was identified by applying the benchmark, set as relevant risk increase to the corresponding ERF. In the case of exposure to aircraft noise, the process can be summarized as follows (Table 26).

Table 26. Average exposure levels (L_{den}) for priority health outcomes from aircraft noise

Summary of priority health outcome evidence	Benchmark level	Evidence quality
Incidence of IHD A relevant risk increase from exposure to aircraft noise occurs at 52.6 dB L_{den} . The weighted average of the lowest noise levels measured in the studies was 47 dB L_{den} and the corresponding RR in the meta-analysis was 1.09 per 10 dB.	5% increase of RR	Very low quality
Incidence of hypertension One study met the inclusion criteria. There was no significant increase of risk associated with increased noise exposure in this study.	10% increase of RR	Low quality
Prevalence of highly annoyed population There was an absolute risk of 10% at a noise exposure level of 45.4 dB L_{den} .	10% absolute risk	Moderate quality
Permanent hearing impairment	No increase	No studies met the inclusion criteria
Reading skills and oral comprehension in children A relevant risk increase was found at 55 dB L_{den} .	One-month delay	Moderate quality

Based on the evaluation of evidence on relevant risk increases from the prioritized health outcomes, the GDG set a guideline exposure level of 45.4 dB L_{den} for average exposure to aircraft noise, based on the absolute %HA. It was confident that there was an increased risk for annoyance below this exposure level, but probably no relevant risk increase for other priority health outcomes. In accordance with the defined rounding procedure, the value was rounded to 45 dB L_{den} . As the evidence on the adverse effects of aircraft noise was rated moderate quality, the GDG made the recommendation strong.

Next, the GDG considered the evidence for night noise exposure and its effect on sleep disturbance (Table 27).

Table 27. Night-time exposure levels (L_{night}) for priority health outcomes from aircraft noise

Summary of priority health outcome evidence	Benchmark level	Evidence quality
Sleep disturbance 11% of participants were highly sleep-disturbed at a noise level of 40 dB L_{night} *	3% absolute risk	Moderate quality

Based on the evidence of the adverse effects of aircraft noise on sleep disturbance, the GDG defined a guideline exposure level of 40.0 dB L_{night} . It should be stressed that this recommendation for average aircraft noise levels at night far exceeds the benchmark of 3%HSD defined as relevant risk increase, but since no reliable acoustic data below this level were available, the GDG decided not to lower the guideline exposure level further, as an extrapolation of the exposure–response relationship to achieve these values would have been unavoidable. As the evidence was rated moderate quality, the GDG made the recommendation strong.

The GDG also considered the evidence for the effectiveness of interventions. The results showed that changes in infrastructure (opening and/or closing of runways, or flight path rearrangements) can lead to a reduction in aircraft noise exposure, as well as a decline in cognitive impairment in children and a reduction in annoyance. Moreover, examples of best practice already exist for the management of noise from aircraft, so the GDG made a strong recommendation.

3.3.1.1 Other factors influencing the strength of recommendations

Other factors considered in the context of recommendations on aircraft traffic noise included those related to values and preferences, benefits and harms, resource implications, equity, acceptability and feasibility; moreover, nonpriority health outcomes were considered. Ultimately, the assessment of all these factors did not lead to a change in the strength of the recommendations. Further details are provided in section 3.3.2.3.

3.3.2 Detailed overview of the evidence

The following sections provide a detailed overview of the evidence constituting the basis for setting the recommendations on aircraft noise. It is presented and summarized separately for each of the critical health outcomes, and the GDG's judgement of the quality of evidence is indicated (for a detailed overview of the evidence on important health outcomes, see Annex 4). Research into health outcomes and effectiveness of interventions is addressed consecutively.

A comprehensive summary of all evidence considered for each of the critical and important health outcomes can be found in the eight systematic reviews published in the *International Journal of Environmental Research and Public Health* (see section 2.3.2 and Annex 2).

3.3.2.1 Evidence on health outcomes

The key question posed was: in the general population exposed to aircraft noise, what is the exposure–response relationship between exposure to aircraft noise (reported as various noise indicators) and the proportion of people with a validated measure of health outcome, when adjusted for main confounders? A summary of the PICOS/PECCOS scheme applied and the main findings is set out in Tables 28 and 29.



Table 28. PICOS/PECCOS scheme of critical health outcomes for exposure to aircraft noise

PECO	Description
Population	General population
Exposure	Exposure to high levels of noise produced by aircraft traffic (average/night time)
Comparison	Exposure to lower levels of noise produced by aircraft traffic (average/night time)
Outcome(s)	For average noise exposure: For night noise exposure: 1. cardiovascular disease 1. effects on sleep 2. annoyance 3. cognitive impairment 4. hearing impairment and tinnitus 5. adverse birth outcomes 6. quality of life, well-being and mental health 7. metabolic outcomes

Table 29 .Summary of findings for health effects from exposure to aircraft noise (L_{den})

Noise metric	Priority health outcome measure	Quantitative risk for adverse health	Lowest level of exposure across studies	Number of participants (studies) ^a	Quality of evidence
Cardiovascular disease					
L_{den}	Incidence of IHD	RR = 1.09 (95% CI: 1.04–1.15) per 10 dB increase	47 dB	9 619 082 ^a (2)	Very low (downgraded for risk of bias; upgraded for dose-response)
L_{den}	Incidence of hypertension	RR = 1.00 (95% CI: 0.77–1.30) per 10 dB increase	N/A	4712 (1)	Low (downgraded for risk of bias and because only one study available)
Annoyance					
L_{den}	%HA	OR = 4.78 (95% CI: 2.27–10.05) per 10 dB increase	33 dB	17 094 (12)	Moderate (downgraded for inconsistency)
Cognitive impairment					
L_{den}	Reading and oral comprehension	1–2-month delay per 5 dB increase	Around 55 dB	(4)	Moderate (downgraded for inconsistency)
Hearing impairment and tinnitus					
L_{den}	Permanent hearing impairment	–	–	–	–

Note: ^a Results are partly derived from population-based studies.

Cardiovascular disease

IHD

No cohort or case-control studies on the relationship between aircraft noise and IHD are available. However, two ecological studies were identified that provide information on the relationship between aircraft noise and incidence (hospital admission) of IHD (Correia et al., 2013; Hansell et al., 2013). These involved a total of 9 619 082 participants, including 158 977 cases. The RR was 1.09 (95% CI: 1.04–1.15) per 10 dB L_{den} increase, and the lowest exposure range was ≤ 51 dB and < 45 dB. Given the weights in the meta-analysis of these two studies, the weighted average starting level was calculated as 47 dB. The evidence was rated very low quality.

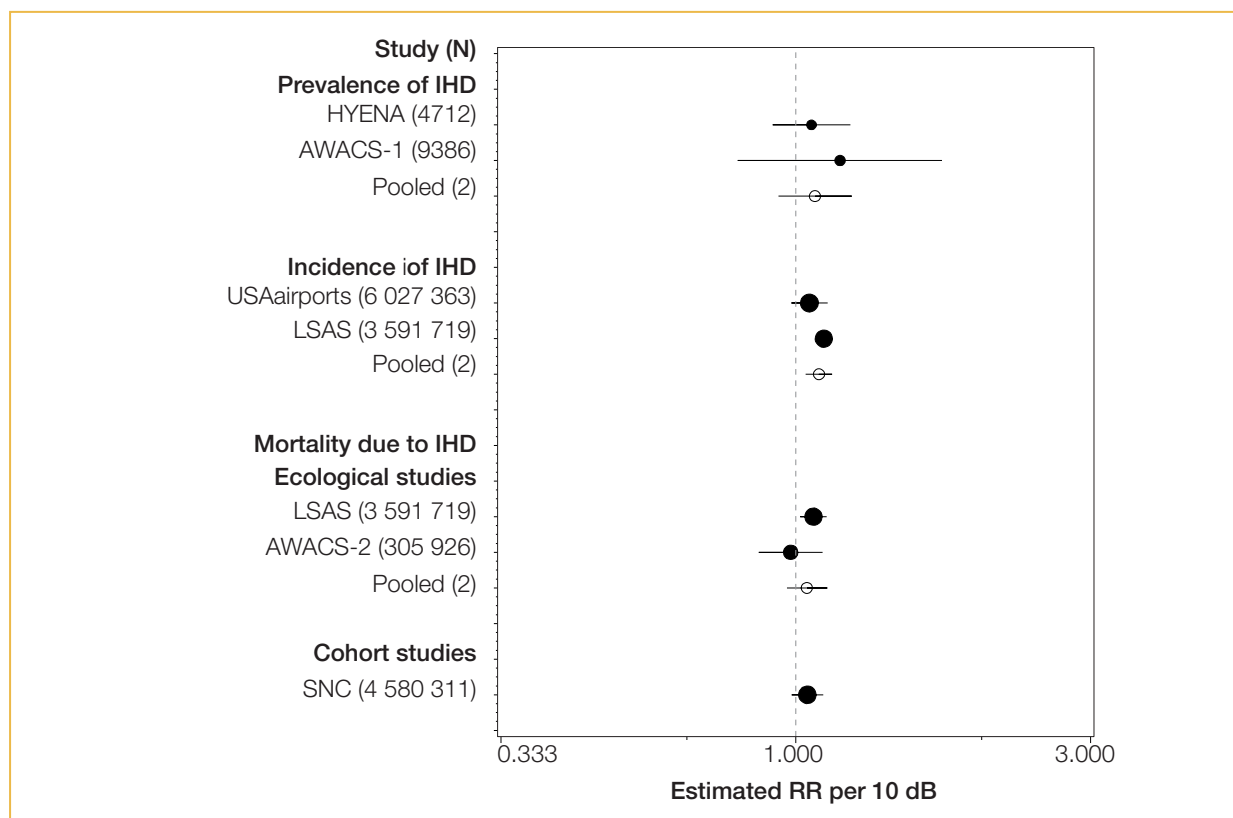
Two cross-sectional studies were identified that assessed the prevalence of IHD in people living in cities located around airports in Europe. The studies involved 14 098 participants, including 340 cases (Babisch et al., 2005b; 2008; 2012a; 2012b; 2013a; Floud et al., 2011; 2013a; 2013b; Jarup et al., 2005; 2008; van Poll et al., 2014). The overall risk was RR = 1.07 (95% CI: 0.94–1.23) per 10 dB L_{den} increase. The evidence was rated low quality.

With regard to the relationship between aircraft noise and mortality due to IHD, one cohort study (Huss et al., 2010) and two ecological studies (Hansell et al., 2013; van Poll et al., 2014) were identified. The cohort study identified 4 580 311 participants, including 15 532 cases, living in Switzerland, and the authors found an RR of 1.04 (95% CI: 0.98–1.11) per 10 dB L_{den} increase in noise. The evidence was rated low quality. The two ecological studies identified a total of 3 897 645

participants, including 26 066 cases in the Netherlands and the United Kingdom. The overall RR was 1.04 (95% CI: 0.97–1.12) per 10 dB L_{den} increase in noise, and the evidence was rated very low quality.

Fig. 10 summarizes the results for the relationship between aircraft noise and different measures of IHD.

Fig. 10. The association between exposure to aircraft noise (L_{den}) and IHD



Notes: The dotted vertical line corresponds to no effect of exposure to aircraft noise. The black circles correspond to the estimated RR per 10 dB and 95% CI. The white circles represent the pooled random effect estimates and 95% CI. For further details on the studies included in the figure please refer to the systematic review on environmental noise and cardiovascular and metabolic effects (van Kempen et al., 2018).

Hypertension

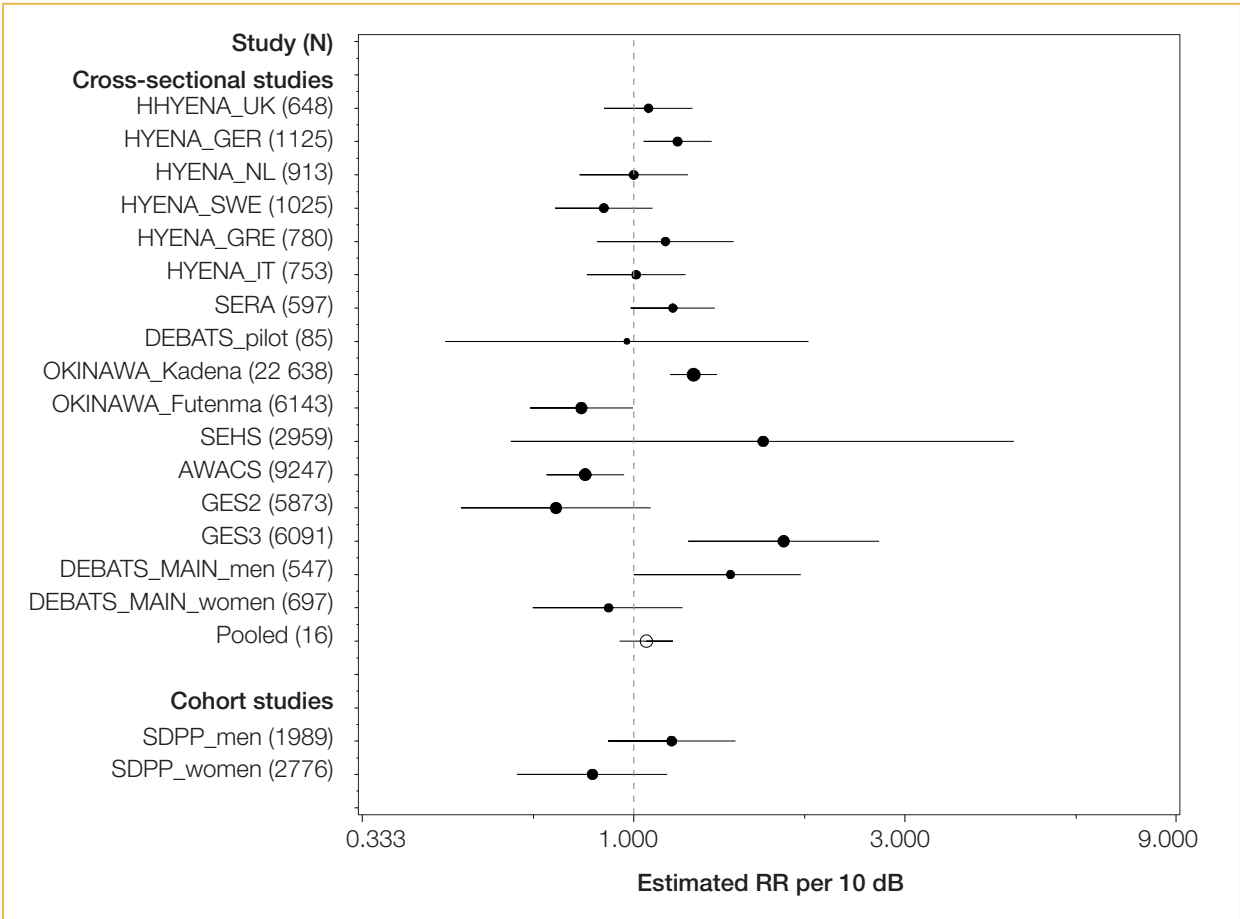
One cohort study was identified that assessed the relationship between aircraft noise and hypertension in people living in Sweden (Bluhm et al., 2004; 2009; Eriksson et al., 2007; 2010). The study involved 4712 participants, including 1346 cases. The authors found a nonstatistically significant effect size of RR = 1.00 (95% CI: 0.77–1.30) per 10 dB L_{den} increase. This evidence was rated moderate quality.

Furthermore, nine cross-sectional studies assessed the prevalence of hypertension in 60 121 participants, including 9487 cases (Ancona et al., 2010; Babisch et al., 2005b; 2008; 2012a; 2012b; 2013a; Breugelmans et al., 2004; Evrard et al., 2013; 2015; Houthuijs & van Wiechen, 2006; Jarup

et al., 2005; 2008; Matsui, 2013; Matsui et al., 2001; 2004; Rosenlund et al., 2001; van Kamp et al., 2006; van Poll et al., 2014). The overall RR was 1.05 (95% CI: 0.95–1.17) per 10 dB L_{den} increase, with inconsistency across studies. The evidence was rated low quality.

Fig. 11 summarizes the results for both prevalence and incidence of hypertension.

Fig. 11. The association between exposure to aircraft noise (L_{den}) and hypertension in cross-sectional and cohort studies



Notes: The dotted vertical line corresponds to no effect of aircraft noise exposure. The black dots correspond to the estimated RR per 10 dB and 95% CI. The white circle represents the pooled summary estimate and 95% CI. For further details on the studies included in the figure please refer to the systematic review on environmental noise and cardiovascular and metabolic effects (van Kempen et al., 2018).

Stroke

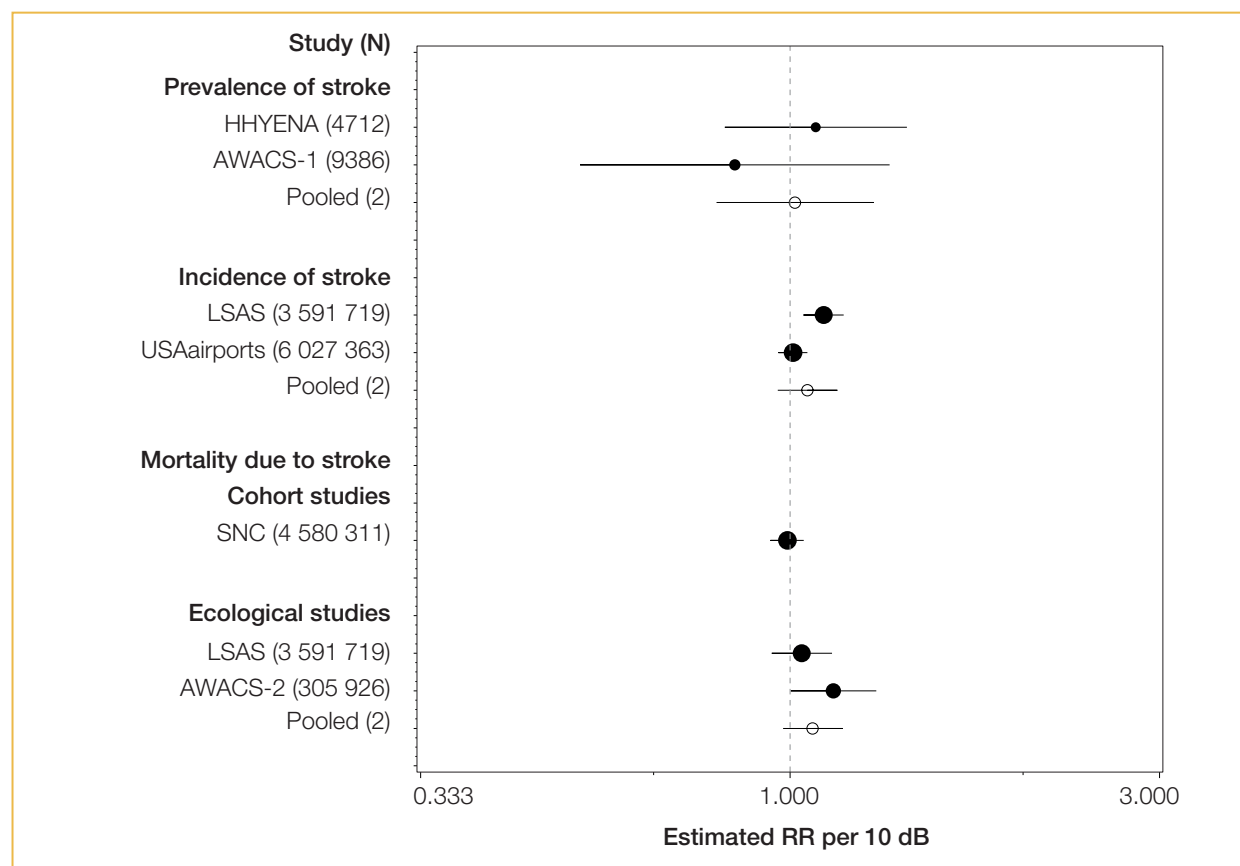
No cohort or case-control studies on the relationship between aircraft noise and incidence (hospital admission) of stroke were available, but two ecological studies were conducted in cities around airports in the United Kingdom and United States of America, involving 9 619 082 participants, including 97 949 cases (Correia et al., 2013; Hansell et al., 2013). An overall RR of 1.05 (95% CI: 0.96–1.15) per 10 dB L_{den} increase in noise was found. The evidence was rated very low quality.

Two cross-sectional studies were identified that assessed the prevalence of stroke in 14 098 participants, including 151 cases (Babisch et al., 2005b; 2008; 2012a; 2012b; 2013a; Floud et al., 2011; 2013a; 2013b; Jarup et al., 2005; 2008; van Poll et al., 2014). The overall RR was 1.02 (95% CI: 0.80–1.28) per 10 dB L_{den} increase. The evidence was rated very low quality.

On the relationship between aircraft noise and mortality due to stroke, one cohort study (Huss et al., 2010) and two ecological studies (Hansell et al., 2013; van Poll et al., 2014) were identified. The cohort study identified 4 580 311 participants, including 25 231 cases, living in Switzerland; the authors found an RR of 0.99 (95% CI: 0.94–1.04) per 10 dB L_{den} increase in noise. The overall evidence was rated moderate quality. The two ecological studies identified a total of 3 897 645 participants, including 12 086 cases, in the Netherlands and the United Kingdom. The overall RR was 1.07 (95% CI: 0.98–1.17) per 10 dB L_{den} increase in noise. The evidence was rated very low quality.

Fig. 12 summarizes the results for the relationship between aircraft noise and different measures of stroke.

Fig. 12. The association between exposure to aircraft noise (L_{den}) and stroke



Notes: The dotted vertical line corresponds to no effect of exposure to aircraft noise. The black dots correspond to the estimated RR per 10 dB and 95% CI. The white circle represents the summary estimate and 95% CI.

For further details on the studies included in the figure please refer to the systematic review on environmental noise and cardiovascular and metabolic effects (van Kempen et al., 2018).

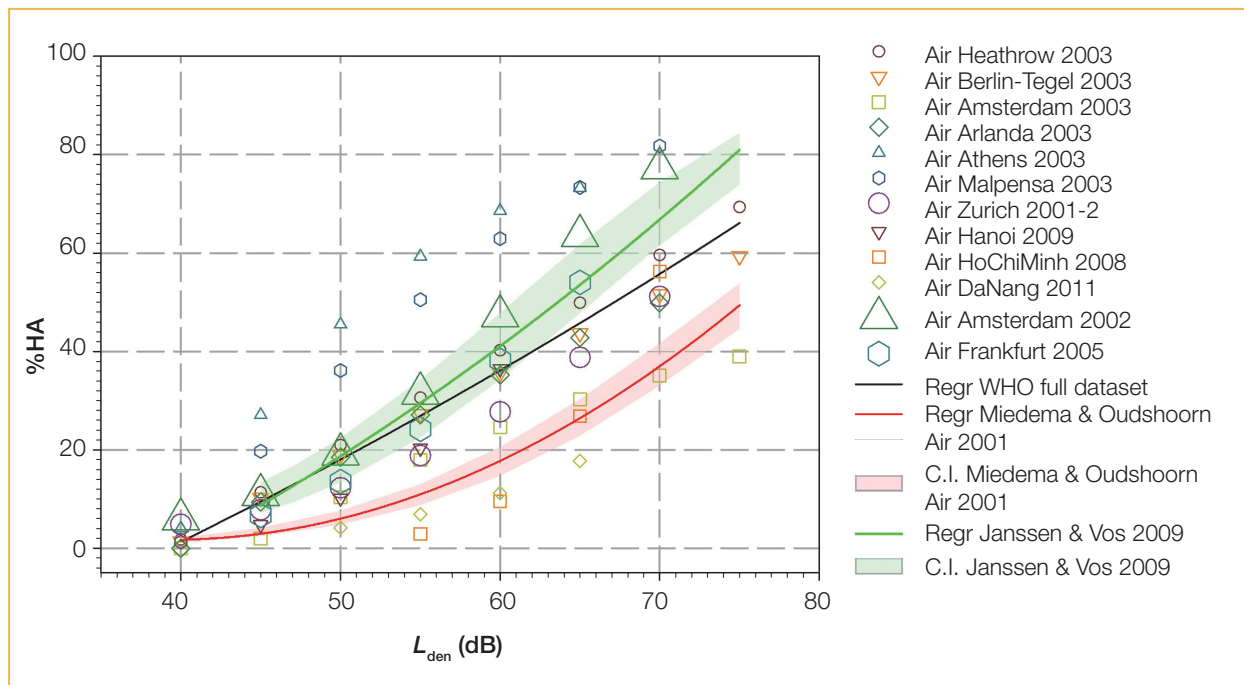
Children's blood pressure

For the association between aircraft noise and blood pressure in children, two cross-sectional studies were conducted in Australia, the Netherlands and the United Kingdom, including a total of 2013 participants (Clark et al., 2012; Morrell et al., 1998; 2000; van Kempen et al., 2006). The change in both systolic and diastolic blood pressure was assessed, in residential and/or educational settings. There was serious inconsistency in the results and therefore no overall estimate of the effect was developed. The evidence was rated very low quality.

Annoyance

A vast amount of evidence proves the association between aircraft noise and annoyance. In total, 12 aircraft noise studies were identified that were used to model ERFs of the relationship between L_{den} and %HA (Babisch et al., 2009; Bartels et al., 2013; Breugelmans et al., 2004; Brink et al., 2008; Gelderblom et al., 2014; Nguyen et al., 2011; 2012a; 2012b; Sato & Yano, 2011; Schreckenber & Meis, 2007). These include data from 17 094 study participants. The estimated data points of each of the studies are plotted in Fig. 13, alongside an aggregated ERF including the data from all the individual studies (see the black line for "Regr WHO full dataset"). The lowest category of noise exposure considered in any of the studies, and hence included in the systematic review, is 40 dB, corresponding to approximately 1.2%HA. The benchmark level of 10%HA is reached at approximately 45 dB L_{den} (see Fig. 13).

Fig. 13. Scatterplot and quadratic regression of the relationship between aircraft noise (L_{den}) and annoyance (%HA)



Notes: ERFs by Miedema & Oudshoorn (2001, red), and Janssen & Vos (2009, green) are added for comparison.

There is no indication of 95% CIs of the WHO dataset curve, as a weighting based on the total number of participants for each 5 dB L_{den} sound class could not be calculated; weighting based on all participants of all sound classes proved to be unsuitable. The range of data included is illustrated by the distribution of data points. For further details on the studies included in the figure please refer to the systematic review on environmental noise and annoyance (Guski et al., 2017).

Table 30 shows the %HA in relation to exposure to aircraft traffic noise. It is based on the regression equation $\%HA = -50.9693 + 1.0168 \times L_{den} + 0.0072 \times L_{den}^2$ derived from the systematic review (Guski et al., 2017). As the majority of the studies are cross-sectional, the evidence was rated moderate quality.

The general quality of the evidence was further substantiated with the help of additional statistical analyses that apply classical health outcome measures to estimate noise annoyance. When comparing aircraft noise exposure at 50 dB and 60 dB, the analyses revealed evidence rated high quality for an association between aircraft noise and %HA for an increase per 10 dB (OR = 3.40; 95% CI: 2.42–4.80). Moreover, there was evidence rated high quality for the increase of %HA per 10 dB increase in sound exposure, when data on all sound classes were included (OR = 4.78; 95% CI: 2.27–10.05).

Table 30. The association between exposure to aircraft noise (L_{den}) and annoyance (%HA)

L_{den} (dB)	%HA
40	1.2
45	9.4
50	17.9
55	26.7
60	36.0
65	45.5
70	55.5



Cognitive impairment

Evidence rated moderate quality was available for an association between aircraft noise and reading and oral comprehension, assessed by standardized tests. This is based on a narrative review of 14 studies that examined aircraft noise exposure effects on reading and oral comprehension (Clark et al., 2006; 2012; 2013; Evans & Maxwell, 1997; Haines et al., 2001a; 2001b; 2001c; Hygge et al., 2002; Klatte et al., 2014; Matsui et al., 2004; Seabi et al., 2012; 2013; Stansfeld et al., 2005; 2010). Of these studies, 10 were cross-sectional, and only four had a longitudinal and/or intervention design (Clark et al., 2013; Haines et al., 2001c; Hygge et al., 2002; Seabi et al., 2013). Most of the studies (10 of 14) demonstrated a statistically significant association or at least demonstrated a trend between higher aircraft noise exposure and poorer reading comprehension.

This relationship is supported by evidence on other health outcome measures related to cognition. Evidence rated moderate quality was available for an association between aircraft noise and children with poorer performance on standardized assessment tests (Eagan et al., 2004; FICAN, 2007; Green et al., 1982; Sharp et al., 2014). There was also evidence rated moderate quality on aircraft noise being associated with children having poorer long-term memory (Haines et al., 2001b). No studies examined the effects on short-term memory.

However, there was no substantial effect (evidence rated low quality) of aircraft noise on children's attention (Haines et al., 2001a; Hygge et al., 2002; Matsui et al., 2004; Stansfeld et al., 2005; 2010), or on executive function (working memory) (evidence rated very low quality), with studies consistently suggesting no association for aircraft noise (Clark et al., 2012; Haines et al., 2001a;

Haines et al., 2001b; Klatte et al., 2014; Matheson et al., 2010; Stansfeld et al., 2005; 2010; van Kempen et al., 2010; 2012).

Hearing impairment and tinnitus

No studies were found, and therefore no evidence was available on the association between aircraft noise and hearing impairment and tinnitus.

Sleep disturbance

For aircraft noise and self-reported sleep outcomes, six studies were identified that included a total of 6371 participants (Nguyen et al., 2009; 2010; 2011; 2012c; 2015; Schreckenberg et al., 2009; Yano et al., 2015). The majority of studies were cross-sectional by design and were conducted in otherwise healthy adults. The model was based on outdoor L_{night} levels between 40 dB and 65 dB only; the lower limit of 40 dB was set because of inaccuracies in predicting lower noise levels (Table 31).

Table 31. Summary of findings for health effects from exposure to aircraft noise (L_{night})

Noise metric	Priority health outcome measure	Quantitative risk for adverse health	Lowest level of exposure across studies	Number of participants (studies)	Quality of evidence
Effects on sleep					
L_{night}	%HSD	OR: 1.94 (95% CI: 1.61–2.33) per 10 dB increase	35 dB	6371 (6)	Moderate (downgraded for study limitations, inconsistency; upgraded for dose-response, magnitude of effect)

The range of noise exposure reported in studies was 37.5–62.5 dB. Over 11% (95% CI: 4.72–17.81) of the population was characterized as highly sleep-disturbed at L_{night} levels of 40 dB. The %HSD at other, higher levels of aircraft noise is presented in Table 27. The table is derived from the regression model in the systematic review specified as $\text{HSD} = 16.79 - 0.9293 \times L_{\text{night}} + 0.0198 \times L_{\text{night}}^2$. The health outcome was measured in the studies by self-reporting, focusing on questions asking about awakenings from sleep, the process of falling asleep and/or sleep disturbance, where the question referred specifically to how noise affects sleep. The same relationship between aircraft noise and reporting being sleep-disturbed (all questions combined) can also be expressed as an OR of 1.94 (95% CI: 1.61–2.33) per 10 dB increase in noise. This evidence was rated moderate quality.

Table 32. The association between exposure to aircraft noise (L_{night}) and sleep disturbance (%HSD)

L_{night}	%HSD	95% CI
40	11.3	4.72–17.81
45	15.0	6.95–23.08
50	19.7	9.87–29.60
55	25.5	13.57–37.41
60	32.3	18.15–46.36
65	40.0	23.65–56.05

Additional analyses were included in the systematic review and provided supporting evidence on the association between aircraft noise and sleep. When the noise source was not specified in the survey question, the relationship between aircraft noise and self-reported sleep outcomes was still positive, although no longer statistically significant (OR: 1.17 (95% CI: 0.54–2.53) per 10 dB increase) (Brink, 2011). This evidence was rated very low quality.

Further, there was evidence rated moderate quality for an association between aircraft noise and polysomnography-measured outcomes (probability of additional awakenings), with an OR of 1.35 (95% CI: 1.22–1.50) per 10 dB increase in indoor $L_{AS,max}$ (Basner et al., 2006). Evidence rated low quality was also available for an association between aircraft noise and motility-measured sleep outcomes in adults (Passchier-Vermeer et al., 2002).

3.3.2.2 Evidence on interventions

The following section summarizes the evidence underlying the recommendation on the effectiveness of interventions for aircraft noise exposure. The key question posed was: in the general population exposed to aircraft noise, are interventions effective in reducing exposure to and/or health outcomes from aircraft noise? A summary of the PICOS/PECCOS scheme applied and the main findings is set out in Tables 33 and 34.

Seven studies examining different types of interventions on aircraft noise met the inclusion criteria to become part of the evidence base of the systematic review. Six of these investigated infrastructure interventions (Breugelmans et al., 2007; Brink et al., 2008; Fidell et al., 2002; Hygge et al., 2002), and one assessed a path intervention (Asensio et al., 2014). The majority of studies focused on annoyance as a health outcome, but two also included effects on sleep and one investigated the effects of path interventions on cognitive development in children.

Table 33. PICOS/PECCOS scheme of the effectiveness of interventions for exposure to aircraft noise

PICO	Description
Population	General population
Intervention(s)	The interventions can be defined as: (a) a measure that aims to change noise exposure and associated health effects; (b) a measure that aims to change noise exposure, with no particular evaluation of the impact on health; or (c) a measure designed to reduce health effects, but that may not include a reduction in noise exposure.
Comparison	No intervention
Outcome(s)	For average noise exposure: 1. cardiovascular disease 2. annoyance 3. cognitive impairment 4. hearing impairment and tinnitus 5. adverse birth outcomes 6. quality of life, well-being and mental health 7. metabolic outcomes For night noise exposure: 1. effects on sleep



Table 34. Summary of findings for aircraft noise interventions by health outcome

Type of intervention	Number of participants (studies)	Effect of intervention	Quality of evidence
Annoyance			
Type B – path interventions (retrofitting dwellings close to airports with acoustic insulation)	689 (1)	- Change in noise levels was not reported. - The study found a drop in annoyance following the insulation intervention	Very low (downgraded for study limitations, inconsistency, precision)
Type C – changes in infrastructure (opening and/or closing of runways, or flight path rearrangements)	2101 (3)	- There was a wide range of changes in noise levels (from –12 dB to +13.7 dB; most between ± 1 dB and 2 dB; different noise indicators used). - All studies found changes in annoyance outcomes as a result of the intervention.	Moderate (downgraded for study limitations; upgraded for dose-response)
Sleep disturbance			
Type C – changes in infrastructure (flight path changes)	1707 (2)	- Changes in noise levels were mostly between ± 1 dB and 2 dB. - Both studies found changes in sleep disturbance outcomes as a result of the intervention.	Low (downgraded for study limitations)
Cognitive development of children			
Type C – changes in infrastructure (opening and/or closing of runways, or flight path rearrangements)	326 (1)	- Changes in noise levels of +9 dB at the new airport and of –14 dB at the old airport were reported. - The study found various cognitive effects on children (for both the reduction and the increase in exposure). Effects disappeared when the old airport closed, emerging after the new airport opened.	Moderate (downgraded for inconsistency)

The largest body of research concentrated on the opening and closing of runways, leading to subsequent changes in flight paths (Breugelmans et al., 2007; Brink et al., 2008; Fidell et al., 2002). It showed that changes in noise exposure as a consequence of rearrangement of flight paths, step changes or increase or removal of over-flights resulted in statistically significant changes of the annoyance ratings of residents living in the vicinity of airports. The studies investigated both increases and reductions in exposure. Moreover, all the studies provided evidence that the change in response to noise exposure was an excess response to the intervention. As all the studies either adjusted for confounding or ruled out confounding by design, and the risk of bias was high in two studies but low in one, the evidence was rated moderate quality.

Two of these studies also investigated the effects of interventions on sleep disturbance. The results indicated that the percentage of sleep disturbance changed in association with the change in noise exposure caused by flight path adaptations (Breugelmans et al., 2007; Fidell et al., 2002). Both studies adjusted for confounding, but the risk of bias was assessed as high. Thus, the evidence was rated low quality.

One study examined the impact of rearranging flight paths on the cognitive effects on children (Hygge et al., 2002), showing various effects (for both the reduction and the increase in exposure).

The study ruled out confounding by study design and the risk of bias was assessed as low. The evidence was therefore rated moderate quality.

Alongside infrastructure interventions, a Spanish study presented evidence on path interventions (Asensio et al., 2014), showing a drop in annoyance following an insulation intervention. The study did not control for confounding and the risk of bias was assessed as high. The evidence was therefore rated very low quality.

3.3.2.3 Consideration of additional contextual factors

As the foregoing overview has shown, substantial evidence about the adverse health effects of long-term exposure to aircraft noise exists. Based on the quality of the available evidence, the GDG set the strength of the recommendation of aircraft noise at strong. As a second step, it qualitatively assessed contextual factors to explore whether other considerations could have a relevant impact on the recommendation strength. These considerations mainly concerned the balance of harms and benefits, values and preferences, equity, and resource use and implementation.

When assessing the balance of harms and benefits from implementing the recommendations on aircraft exposure, the GDG acknowledged that the number of people affected was lower than for road traffic or railway noise, since aircraft noise only affects the areas surrounding airports and under flight paths. Data from the EEA show that the estimated number of people in Europe exposed to L_{den} levels above 55 dB and L_{night} levels above 50 dB is 3 million and 1.2 million, respectively (Blanes et al., 2017).¹⁷ Nevertheless, it remains a major source of localized noise pollution and has been predicted to increase (EASA et al., 2016). Furthermore, aircraft noise is regarded as more annoying than the other sources of transportation noise (Schreckenberg et al., 2015; Miedema & Oudshoorn, 2001); it is therefore associated with a significant burden on public health, and the GDG expects substantial health benefits for the population to evolve from implementing the recommendations to reduce exposure to aircraft traffic noise. Furthermore, the GDG noted that, depending on the intervention measure implemented (such as a night flight ban), additional health benefits could evolve, resulting from a simultaneous reduction in air pollution (EC, 2016a). The GDG also acknowledged that intervention measures like night flight bans might also reduce carbon emission, thereby positively influencing the shift towards a greener and more sustainable economy. Possible harms in relation to the applied noise abatement strategy, on the other hand, could include effects on the transportation of goods, as well as individual mobility of the population. Both could have impacts on local, national and international economies. Overall, the GDG estimated that the benefits gained from minimizing adverse health effects due to aircraft noise exposure outweigh the possible (economic) harms.

Considering values and preferences, the GDG noted that negative attitudes towards aircraft noise are especially prevalent in affected individuals who can see and hear aircraft from their house, or who fear that living in proximity of airports will have an impact on their health (Schreckenberg et al., 2015) or property value (economic loss) (Bristow et al., 2014). A lack of trust in the airport and government authorities can enhance these negative attitudes towards airports and aircraft noise (Borsky, 1979; Schreckenberg, 2017). Furthermore, the GDG recognized that values and preferences of individuals living in the vicinity of different airports may vary, as the infrastructural characteristics

¹⁷ These are gap-filled figures based on the reported data and including the situation both within and outside cities, as defined by the END.



of airports have a significant effect on the evaluation of residents. Airports with a stable number of aircraft movements in the near past and no intention to change the number in the future can give rise to a different evaluation of values and preferences than airports with relatively sustained increases in the number of aircraft movements. This can result from the fact that opening new runways or increasing the number of flights usually means considerable change in the environment for inhabitants of the affected area. It has been postulated that the change of exposure itself may be an annoying factor, and this may explain why aircraft noise annoyance is generally higher than that for other sources of transportation noise at a comparable noise level (Brown & van Kamp, 2009). The GDG acknowledged that, in general, air travel is an important means of transportation relevant for businesses, the public and the economy. In Europe, aviation is projected to be the fastest-growing sector from passenger transport demand, by 2050 (EEA, 2016a). The general population tends to value the convenience of travel by air. Moreover, the GDG pointed out that exposure to aircraft noise is not equally distributed throughout society. The preferences of people living in the vicinity of airports are expected to differ from those of the general population that does not experience the same noise burden. This might facilitate variance in the values and preference of the population, as those benefiting from the services and revenues generated by an airport may regard noise reduction measures as an additional, unnecessary extra cost, while those living around an airport and affected by aircraft noise may be in favour of noise reductions, since this concerns their health and well-being. Despite these differences, however, the GDG was confident that a majority of the population would value the minimization of adverse health effects and therefore welcome the implementation of the recommendations.

Regarding the dimension of equity, the GDG highlighted that the risk of exposure to aircraft noise is not equally distributed throughout society. Members of society with a lower socioeconomic status and other disadvantaged groups often live in more polluted and louder areas, including in close proximity to airports (EC, 2016a). In addition to the increased risk of exposure to environmental noise, socioeconomic factors are also associated with increased vulnerability and poorer coping capacities (Karpati et al., 2002).

With resource use and implementation considerations, the GDG acknowledged that the economic evaluation of the health impacts of environmental noise is most elaborate and extensive for aircraft noise (Berry & Sanchez, 2014). Nevertheless, no comprehensive cost-benefit analysis for the WHO European Region yet exists, so this assessment is based on informed qualitative expert judgement regarding the feasibility of implementing the recommendation for the majority of the population. The systematic review of interventions and their associated impact on environmental noise and health shows that various measures to reduce continuous noise from aircraft exist. Moreover, the quality of the evidence was judged to be moderate (Brown & van Kamp, 2017). The GDG noted that the resources needed to implement different intervention measures may vary considerably, because they depend on the situation and the type of intervention required. The distribution of costs also differs from that for other modes of transportation, since exposure to aircraft noise is localized in a more agglomerated way, and overall the population affected is smaller compared to other modes of transportation. The GDG furthermore recognized that multiple cost-effective intervention strategies exist (EC, 2016b). Prohibition or discouragement strategies against citizens moving to the direct proximity of airports, for example, can be implemented in the context of urban planning. Likewise, diverting flight paths above less-populated areas can lead to a reduction in exposure. In principle,

such intervention measures do not involve any direct costs, although safety concerns may limit the feasibility of these strategies. Passive noise abatement measures like the installation of soundproof windows at the dwelling were also regarded as feasible and economically reasonable by the GDG, as these are implemented at several airports already. In relation to active abatement measures, the GDG acknowledged the “balanced approach” elaborated by International Civil Aviation Organization, which states that noise reduction should take place first at the source. As indicated by the Clean Sky Programme, this could, for example, entail shifting towards the introduction of new aircraft. This broad European research programme estimates that, depending on type, the shift to newly produced aircraft could lead to a reduction of approximately 55–79% of the area affected by aircraft noise, and consequently the population exposed. As this solution has been put forward by the aviation sector, it is considered feasible. Overall, this indicates that solutions to achieve recommended noise levels can be implemented and at reasonable costs. The GDG agreed that implementation of the recommendation to minimize the risk of adverse health effects due to aircraft noise for a majority of the population would require a reasonable amount of (monetary) resources. It noted, however, that the feasibility of implementing the measures could be hindered by the fact that costs and benefits are not equally distributed. In most cases, the health benefits citizens gain from interventions that reduce aircraft exposure are borne by private companies and public authorities.

In light of the assessment of the contextual factors in addition to the quality of evidence, the recommendation remains strong.

Other nonpriority adverse health outcomes

Although not a priority health outcome and coming from a single study, the GDG noted the evidence rated moderate quality for the statistically significant association between aircraft noise and the change in waist circumference (Eriksson et al., 2014). The range of noise levels in the study identified was 48 to 65 dB L_{den} , and therefore the recommendation would also be protective enough for this health outcome.

In the context of aircraft noise, when considering the impacts of exposure on cognitive impairment in children, these guideline recommendations also apply particularly to the school setting. Noise exposure at primary school and at home is often highly correlated; however, the evidence base considered comes mainly from studies designed around sampling at school and not residences.

Additional considerations or uncertainties

There is additional uncertainty when characterizing exposure using the acoustical description of aircraft noise by means of L_{den} or L_{night} . Use of these average noise indicators may limit the ability to observe associations between exposure to aircraft noise and some health outcomes (such as awakening reactions); as such, noise indicators based on the number of events (such as the frequency distribution of $L_{A,max}$) may be better suited. However, such indicators are not widely used.

The GDG acknowledged that the guideline recommendation for L_{night} may not be fully protective of health, as it implies that around 11% (95% CI: 4.72–17.81) of the population may be characterized as highly sleep-disturbed at the recommended L_{night} level. This is higher than the 3% absolute risk considered for setting the guideline level. However, the high calculation uncertainty in predicting noise levels lower than 40 dB prevented the GDG from recommending a lower level. Furthermore,



lower levels would probably require a ban on night or early morning flights altogether, which is not feasible in many situations, given that the general population tends to value the convenience of air travel.

3.3.3 Summary of the assessment of the strength of recommendation

Table 35 provides a comprehensive summary of the different dimensions for the assessment of the strength of the aircraft noise recommendations.

Table 35. Summary of the assessment of the strength of the recommendation

Factors influencing the strength of recommendation	Decision
Quality of evidence	Average exposure (L_{den}) <i>Health effects</i> • Evidence for a relevant RR increase of the incidence of IHD at 52 dB L_{den} was rated very low quality. • Evidence for a relevant RR increase of the incidence of hypertension was rated low quality. • Evidence for a relevant absolute risk of annoyance at 45 dB L_{den} was rated moderate quality. • Evidence for a relevant RR increase of impaired reading and oral comprehension at 55 dB L_{den} was rated moderate quality. <i>Interventions</i> • Evidence on effectiveness of interventions to reduce noise exposure and/or health outcomes from aircraft noise was of varying quality. Night-time exposure (L_{night}) <i>Health effects</i> • Evidence for a relevant absolute risk of sleep disturbance related to night noise exposure from aircraft at 40 dB L_{night} was rated moderate quality. <i>Interventions</i> • Evidence on effectiveness of changes in infrastructure (flight path changes) to reduce sleep disturbance from aircraft noise was rated low quality.
Balance of benefits versus harms and burdens	Aircraft noise is a major source of localized noise pollution. The health benefits of adapting the recommendations are expected to outweigh the harms.
Values and preferences	Quiet areas are valued by the population, especially by those affected by continuous aircraft noise exposure. Some variability is expected among those directly affected by aircraft noise and those not affected.
Equity	Risk of exposure to aircraft noise is not equally distributed.
Resource implications	No comprehensive cost–effectiveness analysis data are available; nevertheless, a wide variety of interventions exist (some at very low cost), indicating that measures are both feasible and economically reasonable.
Decisions on recommendation strength	• Strong for guideline value for average noise exposure (L_{den}) • Strong for guideline value for night noise exposure (L_{night}) • Strong for specific interventions to reduce noise exposure



3.4 Wind turbine noise

Recommendations

For average noise exposure, the GDG **conditionally** recommends reducing noise levels produced by wind turbines below **45 dB L_{den}** , as wind turbine noise above this level is associated with adverse health effects.

To reduce health effects, the GDG **conditionally** recommends that policy-makers implement suitable measures to reduce noise exposure from wind turbines in the population exposed to levels above the guideline values for average noise exposure. No evidence is available, however, to facilitate the recommendation of one particular type of intervention over another.

3.4.1 Rationale for the guideline levels for wind turbine noise

The exposure levels were derived in accordance with the prioritizing process of critical health outcomes described in section 2.4.3. For each of the outcomes, the exposure level was identified by applying the benchmark, set as relevant risk increase to the corresponding ERF. In the case of exposure to wind turbine noise, the process can be summarized as follows (Table 36).

Table 36. Average exposure levels (L_{den}) for priority health outcomes from wind turbine noise

Summary of priority health outcome evidence	Benchmark level	Evidence quality
Incidence of IHD Incidence of IHD could not be used to assess the exposure level.	5% increase of RR	No studies were available
Incidence of hypertension Incidence of hypertension could not be used to assess the exposure level.	10% increase of RR	No studies were available
Prevalence of highly annoyed population Four studies were available. An exposure–response curve of the four studies revealed an absolute risk of 10%HA (outdoors) at a noise exposure level of 45 dB L_{den} .	10% absolute risk	Low quality
Permanent hearing impairment	No increase	No studies were available
Reading skills and oral comprehension in children	One-month delay	No studies were available

In accordance with the prioritization process, the GDG set a guideline exposure level of 45.0 dB L_{den} for average exposure, based on the relevant increase of the absolute %HA. The GDG stressed that there might be an increased risk for annoyance below this noise exposure level, but it could not state whether there was an increased risk for the other health outcomes below this level owing to a lack of evidence. As the evidence on the adverse effects of wind turbine noise was rated low quality, the GDG made the recommendation conditional.

Next, the GDG considered the evidence for night noise exposure to wind turbine noise and its effect on sleep disturbance (Table 37).



Table 37. Night-time exposure levels (L_{night}) for priority health outcomes from wind turbine noise

Summary of priority health outcome evidence	Benchmark level	Evidence quality
Sleep disturbance Six studies were available; they did not reveal consistent results about effects of wind turbine noise on sleep.	3% absolute risk	Low quality

Based on the low quantity and heterogeneous nature of the evidence, the GDG was not able to formulate a recommendation addressing sleep disturbance due to wind turbine noise at night time.

The GDG also looked for evidence about the effectiveness of interventions for wind turbine noise exposure. Owing to a lack of research, however, no studies were available on existing interventions and associated costs to reduce wind turbine noise.

Based on this assessment, the GDG therefore provided a conditional recommendation for average noise exposure (L_{den}) to wind turbines and a conditional recommendation for the implementation of suitable measures to reduce noise exposure. No recommendation about a preferred type of intervention could be formulated; nor could a recommendation be made for an exposure level for night noise exposure (L_{night}), as studies were not consistent and in general did not provide evidence for an effect on sleep.

3.4.1.1 Other factors influencing the strength of recommendation

Other factors considered in the context of recommendations on wind turbine noise included those related to values and preferences, benefits and harms, resource implications, equity, acceptability and feasibility. Ultimately, the assessment of all these factors did not lead to a change in the strength of recommendation, although it informed the development of a conditional recommendation on the intervention measures. Further details are provided in section 3.4.2.3.

3.4.2 Detailed overview of the evidence

The following sections provide a detailed overview of the evidence constituting the basis for setting the recommendations on wind turbine noise. It is presented and summarized separately for each of the critical health outcomes, and the GDG's judgement of the quality of evidence is indicated (for a detailed overview of the evidence on important health outcomes, see Annex 4). Research into health outcomes and effectiveness of intervention is addressed consecutively.

A comprehensive summary of all evidence considered for each of the critical and important health outcomes can be found in the eight systematic reviews published in the *International Journal of Environmental Research and Public Health* (see section 2.3.2 and Annex 2).

It should be noted that, due to the time stamp of the systematic reviews, some more recent studies were not included in the analysis. This relates in particular to several findings of the Wind Turbine Noise and Health Study conducted by Health Canada (Michaud, 2015). Further, some studies were omitted, as they did not meet the inclusion criteria, including, for instance, studies using distance to the wind turbine instead of noise exposure to investigate health effects. The justification for including and excluding studies is given in the systematic reviews (Basner & McGuire, 2018; Brown et al.,

2017; Clark & Paunovic, 2018; in press; Guski et al., 2017; Nieuwenhuijsen et al., 2017; Śliwińska-Kowalska & Zaborowski, 2017; van Kempen et al., 2018; see Annex 2 for further details).

3.4.2.1 Evidence on health outcomes

The key question posed was: in the general population exposed to wind turbine noise, what is the exposure–response relationship between exposure to wind turbine noise (reported as various noise indicators) and the proportion of people with a validated measure of health outcome, when adjusted for main confounders? A summary of the PICOS/PECCOS scheme applied and the main findings is set out in Tables 38 and 39.

Table 38. PICOS/PECCOS scheme of critical health outcomes for exposure to wind turbine noise

PECO	Description
Population	General population
Exposure	Exposure to high levels of noise produced by wind turbines (average/night time)
Comparison	Exposure to lower levels of noise produced by wind turbines (average/night time)
Outcome(s)	For average noise exposure: 1. cardiovascular disease 2. annoyance 3. cognitive impairment 4. hearing impairment and tinnitus 5. adverse birth outcomes 6. quality of life, well-being and mental health 7. metabolic outcomes For night noise exposure: 1. effects on sleep



Table 39. Summary of findings for health effects from exposure to wind turbine noise (L_{den})

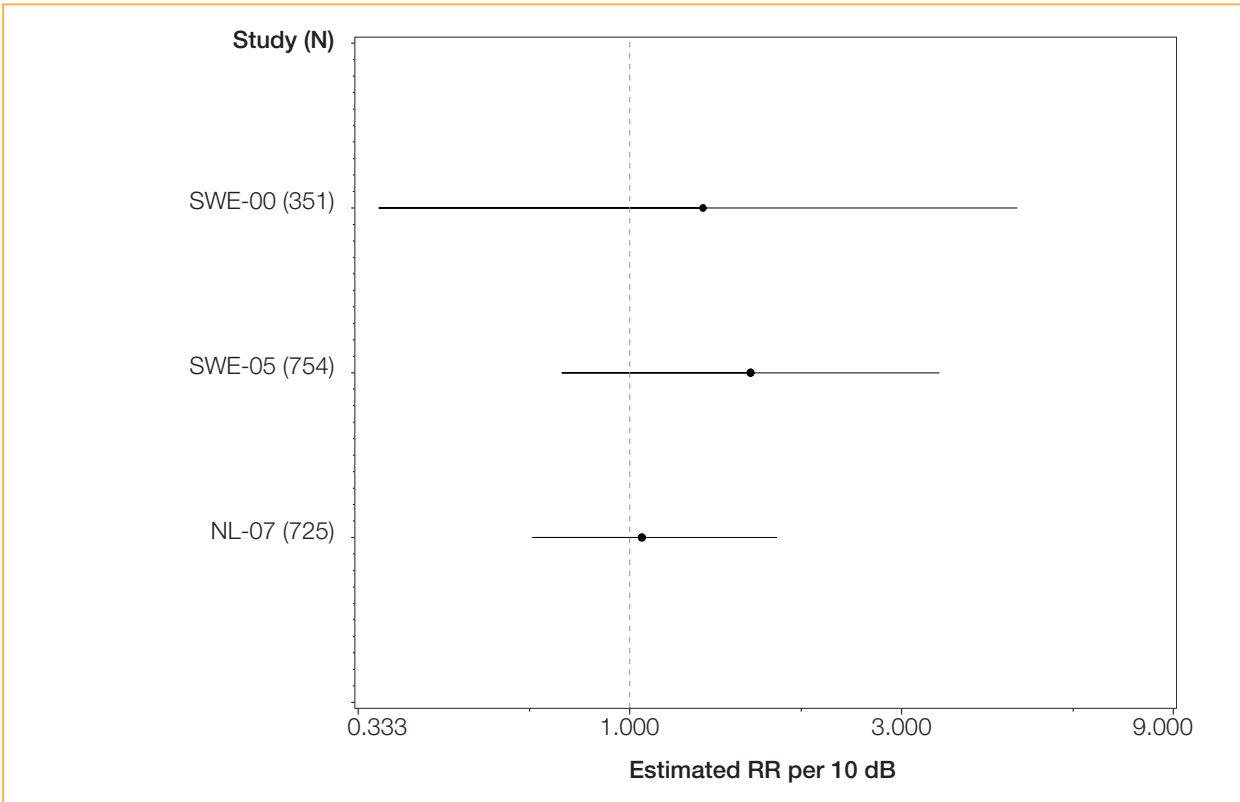
Noise metric	Priority health outcome measure	Quantitative risk for adverse health	Lowest level of exposure across studies	Number of participants (studies)	Quality of evidence
Cardiovascular disease					
L_{den}	Incidence of IHD	–	–	–	–
L_{den}	Incidence of hypertension	–	–	–	–
Annoyance					
L_{den}	%HA	Not able to pool because of heterogeneity	30 dB	2481 (4)	Low (downgraded for inconsistency and imprecision)
Cognitive impairment					
L_{den}	Reading and oral comprehension	–	–	–	–
Hearing impairment and tinnitus					
L_{den}	Permanent hearing impairment	–	–	–	–

Cardiovascular disease

For the relationship between wind turbine noise and prevalence of hypertension, three cross-sectional studies were identified, with a total of 1830 participants (van den Berg et al., 2008; Pedersen, 2011; Pedersen & Larsman, 2008; Pedersen & Persson Waye, 2004; 2007). The number of cases was not reported. All studies found a positive association between exposure to wind turbine noise and the prevalence of hypertension, but none was statistically significant. The lowest levels in studies were either <30 or $<32.5 L_{den}$. No meta-analysis was performed, since too many parameters were unknown and/or unclear. Due to very serious risk of bias and imprecision in the results, this evidence was rated very low quality (see Fig. 14).

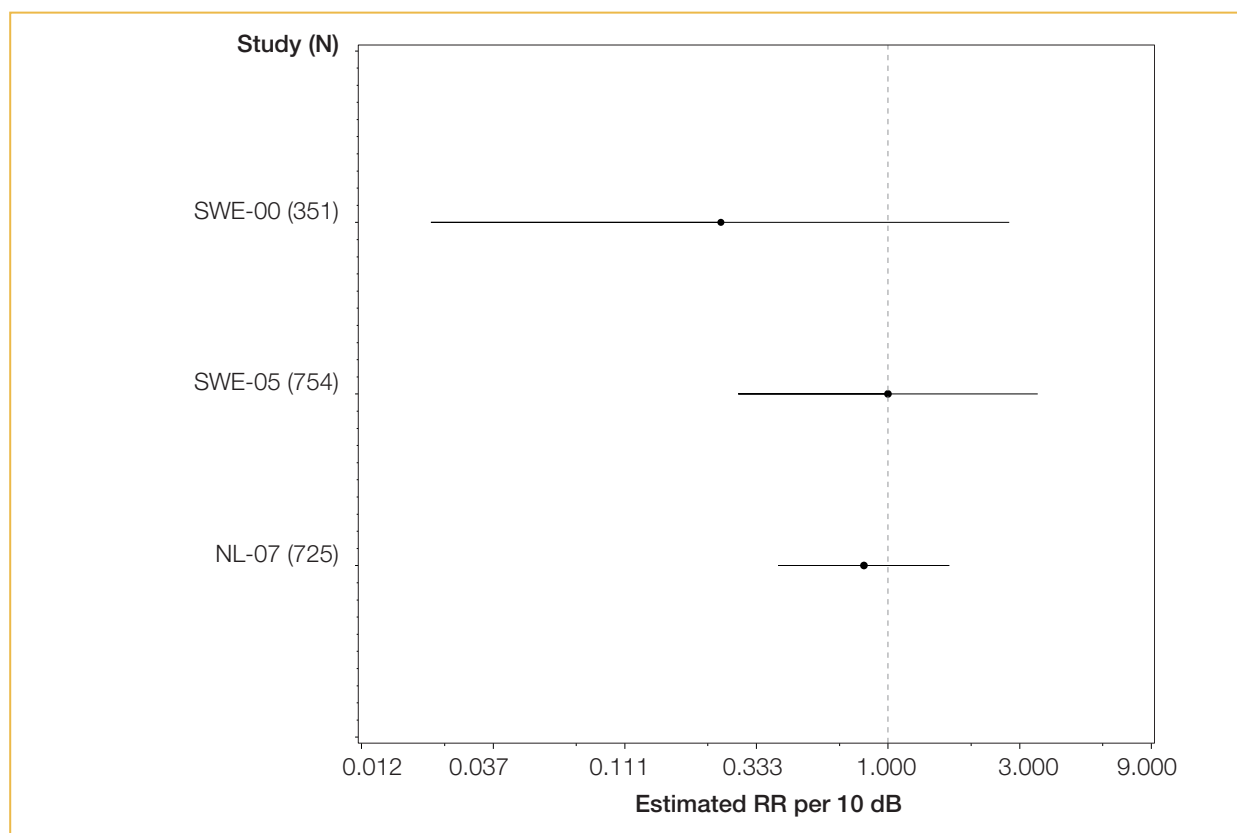
The same studies also looked at exposure to wind turbine noise and self-reported cardiovascular disease, but none found an association. No evidence was available for other measures of cardiovascular disease. As a result, only evidence rated very low quality was available for no considerable effect of audible noise (greater than 20 Hz) from wind turbines or wind farms on self-reported cardiovascular disease (see Fig. 15).

Fig. 14. The association between exposure to wind turbine noise (sound pressure level in dB) and hypertension



Notes: The dotted vertical line corresponds to no effect of exposure to wind turbine noise. The black dots correspond to the estimated RR per 10 dB and 95% CI. For further details on the studies included in the figure please refer to the systematic review on environmental noise and cardiovascular and metabolic effects (van Kempen et al., 2018).

Fig. 15. The association between exposure to wind turbine noise (sound pressure level) and self-reported cardiovascular disease



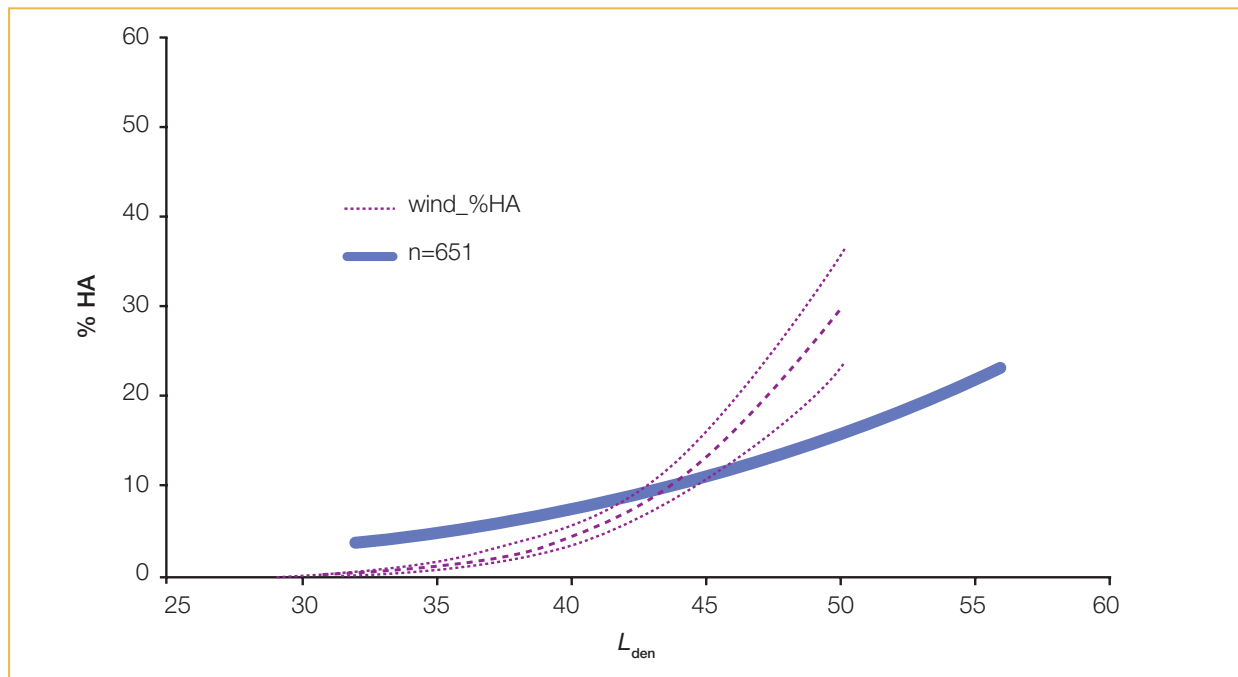
Notes: The dotted vertical line corresponds to no effect of exposure to wind turbine noise. The black circles correspond to the estimated RR per 10 dB (sound pressure level) and 95% CI. For further details on the studies included in the figure please refer to the systematic review on environmental noise and cardiovascular and metabolic effects (van Kempen et al., 2018).

Annoyance

Two publications containing descriptions of four individual studies were retrieved (Janssen et al., 2011; Kuwano et al., 2014). All four studies used measurements in the vicinity of the respondents' addresses; the noise exposure metrics used in the three original studies (Pedersen, 2011; Pedersen & Persson Waye, 2004; 2007) included in Janssen et al. (2011) were recalculated into L_{den} . The noise levels in the studies ranged from 29 dB to 56 dB. Different scales were used to assess annoyance, with slightly different definitions of "highly annoyed" and explicit reference to outdoor annoyance in the data used for the Janssen et al. (2011) curve. Construction of the ERFs provided in the two publications differed and they were therefore not further combined in a meta-analysis. Fig. 16 shows the %HA from the two publications. The 10% criterion for %HA is reached at around 45 dB L_{den} (where the two curves coincide). There was a wide variability in %HA between studies, with a range of 3–13%HA at 42.5 dB and 0–32%HA at 47.5 dB. The %HA in the sample is comparatively high, given the relatively low noise levels. There is evidence rated low quality for an association between wind turbine noise and annoyance, but this mainly applies to the association between wind turbine noise and annoyance and not to the shape of the quantitative relationship.

Further statistical analyses of annoyance yield evidence rated low quality for an association between wind turbine noise and %HA when comparing an exposure at 42.5 dB and 47.5 dB, with a mean difference in %HA of 4.5 (indoors) and 6.4 (outdoors). There is also evidence rated moderate quality for a correlation between individual noise exposure and annoyance raw scores ($r = 0.28$).

Fig. 16. Overlay of the two wind turbine annoyance graphs



Notes: Overlay of the two wind turbine outdoor annoyance graphs adapted from Janssen et al. (2011, red) and Kuwano et al. (2014, blue). The Kuwano et al. curve is based on L_{dn} ; no correction for L_{den} has been applied.¹⁸ For further details on the studies included in the figure please refer to the systematic review on environmental noise and annoyance (Guski et al., 2017).

Cognitive impairment, hearing impairment and tinnitus, adverse birth outcomes

No studies were found, and therefore no evidence was available on the relationship between wind turbine noise and measures of cognitive impairment; hearing impairment and tinnitus; and adverse birth outcomes.

Sleep disturbance

Six cross-sectional studies on wind turbine noise and self-reported sleep disturbance were identified (Bakker et al., 2012; Kuwano et al., 2014; Michaud, 2015; Pawlaczek-Luszczynska et al., 2014; Pedersen & Persson Waye, 2004; 2007). Noise levels were calculated using different methods, and different noise metrics were reported. Three of the studies asked how noise affects sleep; the other three evaluated the effect of wind turbine noise on sleep using questions that explicitly referred to noise (Table 40).

¹⁸ L_{dn} is the day-night-weighted sound pressure level as defined in section 3.6.4 of ISO 1996-1:2016.

Table 40. Summary of findings for health effects from exposure to wind turbine noise (L_{night})

Noise metric	Priority health outcome measure	Quantitative risk for adverse health	Lowest level of effects in studies	Number of participants (studies)	Quality of evidence
Effects on sleep					
L_{night}	%HSD	1.60 (95% CI: 0.86–2.94) per 10 dB increase	31 dB	3971 (6)	Low (downgraded for study limitations, inconsistency, precision)

The risk of bias was assessed as high for all six studies, as effects on sleep were measured by self-reported data. There were a limited number of subjects at higher exposure levels. A meta-analysis was conducted for five of the six studies, based on the OR for high sleep disturbance for a 10 dB increase in outdoor predicted sound pressure level. The pooled OR was 1.60 (95% CI: 0.86–2.94). The evidence was rated low quality.

3.4.2.2 Evidence on interventions

This section summarizes the evidence underlying the recommendation on the effectiveness of interventions for wind turbine noise exposure. The key question posed was: in the general population exposed to wind turbine noise, are interventions effective in reducing exposure to and/or health outcomes from wind turbine noise? A summary of the PICOS/PECCOS scheme applied is set out in Table 41.

Table 41. PICOS/PECCOS scheme of the effectiveness of interventions for exposure to wind turbine noise

PICO	Description
Population	General population
Intervention(s)	The interventions can be defined as: (a) a measure that aims to change noise exposure and associated health effects; (b) a measure that aims to change noise exposure, with no particular evaluation of the impact on health; or (c) a measure designed to reduce health effects, but that may not include a reduction in noise exposure.
Comparison	No intervention
Outcome(s)	For average noise exposure: 1. cardiovascular disease 2. annoyance 3. cognitive impairment 4. hearing impairment and tinnitus 5. adverse birth outcomes 6. quality of life, well-being and mental health 7. metabolic outcomes For night noise exposure: 1. effects on sleep



No studies were found, and therefore no evidence was available on the effectiveness of interventions to reduce noise exposure from wind turbines.

3.4.2.3 Consideration of additional contextual factors

As the foregoing overview has shown, very little evidence is available about the adverse health effects of continuous exposure to wind turbine noise. Based on the quality of evidence available, the GDG set the strength of the recommendation on wind turbine noise to conditional. As a second step, it qualitatively assessed contextual factors to explore whether other considerations could have a relevant impact on the recommendation strength. These considerations mainly concerned the balance of harms and benefits, values and preferences, and resource use and implementation.

Regarding the balance of harms and benefits, the GDG would expect a general health benefit from a marked reduction in any kind of long-term environmental noise exposure. Health effects of individuals living in the vicinity of wind turbines can theoretically be related not only to long-term noise exposure from the wind turbines but also to disruption caused during the construction phase. The GDG pointed out, however, that evidence on health effects from wind turbine noise (apart from annoyance) is either absent or rated low/very low quality (McCunney et al., 2014). Moreover, effects related to attitudes towards wind turbines are hard to discern from those related to noise and may be partly responsible for the associations (Knopper & Ollson, 2011). Furthermore, the number of people exposed is far lower than for many other sources of noise (such as road traffic). Therefore, the GDG estimated the burden on health from exposure to wind turbine noise at the population level to be low, concluding that any benefit from specifically reducing population exposure to wind turbine noise in all situations remains unclear. Nevertheless, proper public involvement, communication and consultation of affected citizens living in the vicinity of wind turbines during the planning stage of future installations is expected to be beneficial as part of health and environmental impact assessments. In relation to possible harms associated with the implementation of the recommendation, the GDG underlined the importance of wind energy for the development of renewable energy policies.

The GDG noticed that the values and preferences of the population towards reducing long-term noise exposure to wind turbine noise vary. Whereas the general population tends to value wind energy as an alternative, environmentally sustainable and low-carbon energy source, people living in the vicinity of wind turbines may evaluate them negatively. Wind turbines are not a recent phenomenon, but their quantity, size and type have increased significantly over recent years. As they are often built in the middle of otherwise quiet and natural areas, they can adversely affect the integrity of a site. Furthermore, residents living in these areas may have greater expectations of the quietness of their surroundings and therefore be more aware of noise disturbance. Negative attitudes especially occur in individuals who can see wind turbines from their houses but do not gain economically from the installations (Kuwano et al., 2014; Pedersen & Persson Waye, 2007; van den Berg et al., 2008). These situational variables and the values and preferences of the population may differ between wind turbines and other noise sources, as well as between wind turbine installations, which makes assessment of the relationship between wind turbine noise exposure and health outcomes particularly challenging.

Assessing resource use and implementation considerations, the GDG noted that reduction of noise exposure from environmental sources is generally possible through simple measures like insulating windows or building barriers. With wind turbines, however, noise reduction interventions are more

complicated than for other noise sources due to the height of the source and because outdoor disturbance is a particularly large factor. As generally fewer people are affected (compared to transportation noise), the expected costs are lower than for other environmental sources of noise. The GDG was not aware of any existing interventions (and associated costs) to reduce harms from wind turbine noise, or specific consequences of having regulations on wind turbine noise. Therefore, it could not assess feasibility, or discern whether any beneficial effects of noise reduction would outweigh the costs of intervention. In particular, there is no clear evidence on an acceptable and uniform distance between wind turbines and residential areas, as the sound propagation depends on many aspects of the wind turbine construction and installation.

In light of the assessment of the contextual factors in addition to the quality of evidence, the recommendation for wind turbine noise exposure remains conditional.

Additional considerations or uncertainties

Assessment of population exposure to noise from a particular source is essential for setting health-based guideline values. Wind turbine noise is characterized by a variety of potential moderators, which can be challenging to assess and have not necessarily been addressed in detail in health studies. As a result, there are serious issues with noise exposure assessment related to wind turbines.

Noise levels from outdoor sources are generally lower indoors because of noise attenuation from the building structure, closing of windows and similar. Nevertheless, noise exposure is generally estimated outside, at the most exposed façade. As levels of wind turbine noise are generally much lower than those of transportation noise, the audibility of wind turbines in bedrooms, particularly when windows are closed, is unknown.

In many instances, the distance from a wind farm has been used as a proxy to determine audible noise exposure. However, in addition to the distance, other variables – such as type, size and number of wind turbines, wind direction and speed, location of the residence up- or downwind from wind farms and so on – can contribute to the resulting noise level assessed at a residence. Thus, using distance to a wind farm as a proxy for noise from wind turbines in health studies is associated with high uncertainty.

Wind turbines can generate infrasound or lower frequencies of sound than traffic sources. However, few studies relating exposure to such noise from wind turbines to health effects are available. It is also unknown whether lower frequencies of sound generated outdoors are audible indoors, particularly when windows are closed.

The noise emitted from wind turbines has other characteristics, including the repetitive nature of the sound of the rotating blades and atmospheric influence leading to a variability of amplitude modulation, which can be a source of above average annoyance (Schäffer et al., 2016). This differentiates it from noise from other sources and has not always been properly characterized. Standard methods of measuring sound, most commonly including A-weighting, may not capture the low-frequency sound and amplitude modulation characteristic of wind turbine noise (Council of Canadian Academies, 2015).

Even though correlations between noise indicators tend to be high (especially between L_{Aeq} -like indicators) and conversions between indicators do not normally influence the correlations between the noise indicator and a particular health effect, important assumptions remain when exposure to



wind turbine noise in L_{den} is converted from original sound pressure level values. The conversion requires, as variable, the statistical distribution of annual wind speed at a particular height, which depends on the type of wind turbine and meteorological conditions at a particular geographical location. Such input variables may not be directly applicable for use in other sites. They are sometimes used without specific validation for a particular area, however, because of practical limitations or lack of data and resources. This can lead to increased uncertainty in the assessment of the relationship between wind turbine noise exposure and health outcomes.

Based on all these factors, it may be concluded that the acoustical description of wind turbine noise by means of L_{den} or L_{night} may be a poor characterization of wind turbine noise and may limit the ability to observe associations between wind turbine noise and health outcomes.

3.4.3 Summary of the assessment of the strength of recommendations

Table 42 provides a comprehensive summary of the different dimensions for the assessment of the strength of the wind turbine recommendations.

Table 42. Summary of the assessment of the strength of the recommendation

Factors influencing the strength of recommendation	Decision
Quality of evidence	Average exposure (L_{den}) <i>Health effects</i> - Evidence for a relevant absolute risk of annoyance at 45 dB L_{den} was rated low quality. <i>Interventions</i> - No evidence was available on the effectiveness of interventions to reduce noise exposure and/or health outcomes from wind turbines. Night-time exposure (L_{night}) <i>Health effects</i> - No statistically significant evidence was available for sleep disturbance related to exposure from wind turbine noise at night. <i>Interventions</i> - No evidence was available on the effectiveness of interventions to reduce noise exposure and/or sleep disturbance from wind turbines.
Balance of benefits versus harms and burdens	Further work is required to assess fully the benefits and harms of exposure to environmental noise from wind turbines and to clarify whether the potential benefits associated with reducing exposure to environmental noise for individuals living in the vicinity of wind turbines outweigh the impact on the development of renewable energy policies in the WHO European Region.
Values and preferences	There is wide variability in the values and preferences of the population, with particularly strong negative attitudes in populations living in the vicinity of wind turbines.
Resource implications	Information on existing interventions (and associated costs) to reduce harms from wind turbine noise is not available.
Additional considerations or uncertainties	There are serious issues with noise exposure assessment related to wind turbines.
Decisions on recommendation strength	Conditional for guideline value for average noise exposure (L_{den}) Conditional for the effectiveness of interventions (L_{night})



3.5 Leisure noise

Recommendations

For average noise exposure, the GDG **conditionally** recommends reducing the yearly average from all leisure noise sources combined to **70 dB $L_{Aeq,24h}$** , as leisure noise above this level is associated with adverse health effects. The equal energy principle¹⁹ can be used to derive exposure limits for other time averages, which might be more practical in regulatory processes.

For single-event and impulse noise exposures, the GDG **conditionally** recommends following existing guidelines and legal regulations to limit the risk of increases in hearing impairment from leisure noise in both children and adults.

Following a precautionary approach, to reduce possible health effects, the GDG **strongly** recommends that policy-makers take action to prevent exposure above the guideline values for average noise and single-event and impulse noise exposures. This is particularly relevant as a large number of people may be exposed to and at risk of hearing impairment through the use of personal listening devices (PLDs). There is insufficient evidence, however, to recommend one type of intervention over another.



3.5.1 Rationale for the guideline levels for leisure noise

As specific evidence for the relationship between leisure noise and hearing loss is of insufficient quality, the GDG decided to follow a different approach for this noise source, based on knowledge regarding prevention of hearing loss in the workplace and on the CNG (WHO, 1999). There is sufficient evidence that the nature of the noise matters little in causing hearing loss, so using the existing guidelines is a justified step to prevent permanent hearing loss from leisure noise.

In accordance with the procedures for the other noise sources, the GDG would have considered evidence on exposure–response relationships for the prioritized health outcomes. However, no such ERFs could be established in the systematic reviews for any of the health outcomes (Table 43).

Table 43. Average exposure levels ($L_{Aeq,24h}$) for priority health outcomes from leisure noise

Summary of priority health outcome evidence	Benchmark level	Evidence quality
Incidence of IHD Incidence of hypertension Prevalence of highly annoyed population Reading skills and oral comprehension in children		No evidence was available
Permanent hearing impairment There is an indication that PLDs have an effect on hearing impairment and tinnitus. There was no evidence (because no studies were found) for an effect of other sources of leisure noise on hearing impairment or tinnitus. The results of the studies could not be synthesized because of heterogeneity of outcome measurement.	No increase	Very low quality/no evidence

¹⁹ The equal energy principle states that the total effect of sound is proportional to the total amount of sound energy received by the ear, irrespective of the distribution of that energy in time (WHO, 1999).

In accordance with the evidence on the effects of PLDs on permanent hearing loss from leisure noise, the GDG recommended a guideline exposure level of 70 dB $L_{Aeq,24h}$ yearly average from all leisure noise sources combined. It was confident that there was no relevant risk increase for permanent hearing impairment below this exposure level of average leisure noise. The GDG recognized that a conversion to alternative time averages for exposure to leisure noise might be helpful for regulatory purposes; thus, a detailed table converting hourly and weekly exposure into yearly averages is provided in the subsection on additional considerations or uncertainties in section 3.5.2.3, Table 49. Furthermore, the GDG recommended sticking to the CNG recommendations for single events to limit the risk of hearing impairment from leisure noise increases for both children and adults (WHO, 1999).²⁰ Due to the nature and limited amount of available evidence, the GDG made the recommendation conditional.

Next, the GDG assessed the evidence for night noise exposure and its effect on sleep disturbance (Table 44).

Table 44. Night-time exposure levels (L_{night}) for priority health outcomes from leisure noise

Summary of priority health outcome evidence	Benchmark level	Evidence quality
Sleep disturbance	3% absolute risk	No evidence was available

Because of a lack of evidence, the GDG was not able to formulate a recommendation addressing sleep disturbance due to leisure noise at night time.

The GDG also looked for evidence about the effectiveness of interventions for leisure noise exposure. Owing to a lack of research, however, no studies were available on existing interventions and associated costs to reduce leisure noise. As no evidence was available, it was not possible to develop a recommendation on any specific type of intervention measure. However, following a precautionary approach, to reduce possible health effects, the GDG made a strong recommendation that policy-makers take action to prevent exposures above the guideline values for average noise and single-event and impulse noise exposures. This is particularly relevant as a large number of people may be exposed to and at risk of hearing impairment through the use of PLDs. There is insufficient evidence, however, to recommend one type of intervention over another.

3.5. 1.1 Other factors influencing the strength of recommendations

Other factors considered in the context of recommendations on leisure noise included those related to values and preferences, benefits and harms, resource implications, equity, acceptability and feasibility; moreover, nonpriority health outcomes were considered. Ultimately, the assessment of all these factors did not lead to a change in the strength of recommendation. Further details are provided in section 3.5.2.3.

²⁰ The GDG acknowledged the scarcity of cohort study-based evidence to define a threshold for hearing damage due to single loud exposures. It initially decided to propose $L_{AF,max} = 110$, but after much discussion it appeared that the conversion of relevant standing limits (expressed in $L_{peak,C}$ and others) lacked sufficient basis.

3.5.2 Detailed overview of the evidence

The following sections provide a detailed overview of the evidence constituting the basis for setting the recommendations on leisure noise. As noted above, however, only limited evidence was available for several of the prioritized health outcomes, so it is presented and summarized for all critical and important health outcomes where possible, along with indications of the GDG's judgement of the quality of evidence. Research into health outcomes and effectiveness of interventions is addressed consecutively.

A comprehensive summary of all evidence considered for each of the critical and important health outcomes can be found in the eight systematic reviews published in the *International Journal of Environmental Research and Public Health* (see section 2.3.2 and Annex 2).

3.5.2.1 Evidence on health outcomes

The key question posed was: in the general population exposed to leisure noise, what is the exposure–response relationship between exposure to leisure noise (reported as various noise indicators) and the proportion of people with a validated measure of health outcome, when adjusted for main confounders? A summary of the PICOS/PECCOS scheme applied and the main findings is set out in Tables 45 and 46.



Table 45. PICOS/PECCOS scheme of critical health outcomes for exposure to leisure noise

PECO	Description
Population	General population
Exposure	Exposure to high levels of noise produced by leisure activities (average/night time)
Comparison	Exposure to lower levels of noise produced by leisure activities (average/night time)
Outcome(s)	For average noise exposure: For night noise exposure: 1. cardiovascular disease 1. effects on sleep 2. annoyance 3. cognitive impairment 4. hearing impairment and tinnitus 5. adverse birth outcomes 6. quality of life, well-being and mental health 7. metabolic outcomes

Table 46. Summary of findings for health effects from exposure to leisure noise ($L_{Aeq,24h}$)

Noise metric	Priority health outcome measure	Quantitative risk for adverse health	Lowest level of exposure across studies ^a	Number of participants (studies)	Quality of evidence
Cardiovascular disease					
$L_{Aeq,24}$	Incidence of IHD	–	–	–	–
$L_{Aeq,24}$	Incidence of hypertension	–	–	–	–
Annoyance					
$L_{Aeq,24}$	%HA	–	–	–	–
Cognitive impairment					
$L_{Aeq,24}$	Reading and oral comprehension	–	–	–	–
Hearing impairment and tinnitus					
$L_{Aeq,24}$	Permanent hearing impairment	Not estimated	–	484 (3)	Very low (downgraded for study limitations, precision)

Hearing impairment and tinnitus

Several types of leisure activity are accompanied by loud sounds, such as attending nightclubs, pubs and fitness classes; live sporting events; concerts or live music venues; listening to loud music through PLDs. This recommendation is informed by a systematic review that assessed the evidence on permanent hearing loss and tinnitus due to exposure to leisure noise (Śliwińska-Kowalska & Zaborowski, 2017). The review identified two existing systematic reviews that summarized recent estimates of the risk of developing permanent hearing loss from the use of PLDs. It did not identify any studies with objective measurement of exposure to any other type of leisure noise.

The Scientific Committee on Emerging and Newly Identified Hazards and Risk (SCENIHR) (EC, 2008b) report concluded that prolonged exposure to sounds from PLDs may result in temporary hearing threshold shift, permanent hearing threshold shift and tinnitus, as well as poor speech communication in noisy conditions. However, based on the data available, there was no direct evidence for an effect of repeated, regular daily exposure to music through PLDs on development of permanent noise-induced hearing loss. Data on tinnitus were inadequate and therefore inconclusive. No meta-analysis was provided for any of the hearing effects; nor were the exposure–effect curves reported. The SCENIHR report was based on a narrative review of 30 original papers with over 2000 participants and exposure to music sounds that covered a range of 60–120 dB. Studies included in the review were carried out between 1982 and 2007.

In 2014 a second systematic review was published by Vasconcellos et al. (2014). Although the objective of this publication was to determine threshold levels of personally modifiable risk factors for hearing loss in the paediatric population, specific thresholds analyses were limited. Based on the descriptive overview of original papers, the authors identified exposure to loud music (including use of PLDs) and working on a mechanized farm as the main risk factors for hearing loss in children

and teenagers. Thresholds of exposure to music, significantly associated with hearing loss in youth, were:

- more than four hours per week or more than five years of personal headphone usage;
- more than four visits per month to a discotheque.

The evidence review identified five new cross-sectional studies on noise from PLDs since the publication of the SCENIHR report (Feder et al., 2013; Levesque et al., 2010; Sulaiman et al., 2013; 2014; Vogel et al., 2014). Direct measurement of hearing thresholds with pure tone audiometry was performed only in three studies – by Feder et al. (2013) and Sulaiman et al. (2013 and 2014). In total, audiometric data from 484 subjects were analysed; among them, 449 were exposed and 35 were not exposed to PLD music. Two other studies by Levesque et al. (2010) and Vogel et al. (2014) did not perform audiometric measurement but reported on tinnitus in a total of 1067 participants.

Noise from PLDs was estimated based on direct measurement of equivalent sound pressure levels (in dB) in four studies (Feder, 2013; Levesque et al., 2010; Sulaiman et al., 2013; 2014) and based on converting volume-control setting levels of PLD into dB levels in one study (Vogel et al., 2014). The resulting exposure levels (L_{Aeq} values) had a mean of between 72 dB and 91 dB, although in two studies these data were not provided. In all studies, individual $L_{Aeq,8h}$ value was calculated based on an estimated level of music and the number of hours a day listening to the music through the PLD declared by an individual in the questionnaire. Resulting $L_{Aeq,8h}$ mean values were between 62 dB and 83 dB when provided.

Potential confounding was controlled by excluding the subjects with exposure to other sources of high-level noise or prior ear problems (Sulaiman et al., 2013), by excluding those with these factors and ototoxic drug intake (Sulaiman et al., 2014) or by controlling for these confounders by accounting for them in the statistical models. The confounders comprised socioeconomic status, demographic factors, tubes in the ear and leisure exposures in one study (Feder, 2013), and age and sex in one study (Vogel et al., 2014). One of the studies did not adjust for confounding factors (Levesque et al., 2010).

Data on permanent hearing loss were taken from audiometric measurements (Feder, 2013; Sulaiman et al., 2013; 2014), while data about permanent tinnitus were taken from self-reported responses to questionnaires (Levesque et al., 2010; Vogel et al., 2014). In one case, the outcome was defined as “permanent hearing-related symptoms”, but it is not clear what proportion of subjects experienced permanent tinnitus (Vogel et al., 2014).

For permanent hearing loss, there is no pooled effect size, because the authors of the original studies either did not report data or reported in different formats. However, these studies indicate a harmful effect of listening to PLDs. For permanent tinnitus, there is no pooled effect size because the effects of noise from PLDs on permanent tinnitus were contradictory. These results are generally consistent with previous reviews by SCENIHR (EC, 2008b) and Vasconcellos et al. (2014).

The risk of bias was assessed as high for all five studies. The overall evidence for an effect of PLDs on hearing impairment and tinnitus was rated very low quality.



3.5.2.2 Evidence on interventions

The following section summarizes the evidence underlying the recommendation on the effectiveness of interventions for leisure noise exposure. The key question posed was: in the general population exposed to leisure noise, are interventions effective in reducing exposure to and/or health outcomes from leisure noise? A summary of the PICOS/PECCOS scheme applied and the main findings is set out in Tables 47 and 48.

Table 47. PICOS/PECCOS scheme of the effectiveness of interventions for exposure to leisure noise

PICO	Description
Population	General population
Intervention(s)	The interventions can be defined as: (a) a measure that aims to change noise exposure and associated health effects; (b) a measure that aims to change noise exposure, with no particular evaluation of the impact on health; or (c) a measure designed to reduce health effects, but that may not include a reduction in noise exposure.
Comparison	No intervention
Outcome(s)	For average noise exposure: 1. cardiovascular disease 2. annoyance 3. cognitive impairment 4. hearing impairment and tinnitus 5. adverse birth outcomes 6. quality of life, well-being and mental health 7. metabolic outcomes For night noise exposure: 1. effects on sleep

Table 48. Summary of findings for interventions for leisure noise

Type of intervention	Number of participants (studies)	Effect of intervention	Quality of evidence
Hearing impairment			
Type E – behaviour change interventions (education programme/campaign)	4151 (7)	None of the studies involved measurement or estimation of exposure levels or health outcomes. Most studies found a significant effect of change in knowledge or behaviour.	–

Seven individual studies on PLDs, attendance at music venues and participation in other recreational activities where there was risk of hearing damage and/or tinnitus were included in the systematic review (Dell & Holmes, 2012; Gilles & Van de Heyning, 2014; Kotowski et al., 2011; Martin et al., 2013; Taljaard et al., 2013; Weichbold & Zorowka, 2003; 2007). All studies examined interventions directed at changes in knowledge or behaviour and hearing impairment.

The studies all sought evidence on the effectiveness of some form of educational programme or campaign aimed at children, adolescents or college students. These addressed perceptions and

knowledge of the risk of high levels of noise – generally, but not exclusively, from PLD sources or from attendance at music events – and actual or intended changes to hearing damage risk behaviours, including avoidance, frequency or duration of exposure, regeneration periods when in high noise, or playback levels.

The outcome assessed in all intervention studies was the change in knowledge and behaviours towards hearing damage risk. The health outcome measures varied widely and included measurements on the youth attitude towards noise scale, participants' knowledge about hearing damage, participants' PLD usage patterns, participants' attitudes to wearing hearing protection (some in general; some at discotheques) and frequency of discotheque attendance. A majority of the studies found a significant effect of change in knowledge or behaviour. No indication on the persistence of knowledge and behavioural change was given, though.

None of the studies included objectively measured outcomes or a measured change in noise level exposure; thus, the effectiveness of the interventions could not be assessed, and the quality of the evidence was not rated according to GRADE.



3.5.2.3 Consideration of additional contextual factors

Based on the quality of the available evidence discussed in the foregoing overview, the GDG set the strength of recommendation of leisure noise to conditional. As a second step, it qualitatively assessed contextual factors to explore whether other considerations could have a relevant impact on the recommendation strength. These considerations mainly concerned the balance of harms and benefits, values and preferences, and resource use and implementation.

When assessing the balance of benefits and harms, the GDG recognized that exposure to leisure noise is widespread and frequent. In particular, as many as 88–90% of teenagers and young adults report listening to music through PLDs earphones (Pellegrino et al., 2013; Vogel et al., 2011). In 2015 WHO estimated that 1.1 billion young people worldwide could be at risk of hearing loss due to unsafe listening practices (WHO, 2015a). Furthermore, among young people aged 12–35 years in middle- and high-income countries, nearly 50% listen to unsafe levels of sound through personal audio devices (mp3 players, smartphones and others), and around 40% are exposed to potentially damaging levels of sound at nightclubs, bars and sporting events. Noise-induced hearing loss can be prevented by following safe listening practices, so the GDG concluded that health benefits can be gained from markedly reducing population exposure to leisure noise, including through actions to promote safe listening practices. A reduction of leisure noise is also assumed to reduce nuisance that can be caused to other people than those who enjoy leisure activities, such as neighbours. Furthermore, specifically for PLDs, it can reasonably be expected that a reduction of noise exposure could also lead to a reduction in accidents, injuries and other potential safety risks. In relation to possible harms and burdens, the GDG could not identify any harms (except economic costs, which are addressed in the paragraph on resource use and implementation) arising from implementation of the recommended guideline values.

Considering values and preferences, the GDG recognized that listening to music with the help of a PLD, going to concerts and attending sport events are activities regarded as enjoyable and therefore assumed to be valued by the overall population. Furthermore, it is expected that values and preferences might vary in particular with respect to the use of PLDs and embracing leisure activities

involving loud noise, like concerts, and that some population groups – especially younger individuals – might voluntarily expose themselves to high levels of sound during these activities. Despite this, the GDG was confident that recommendations to lower noise levels for the prevention of hearing damage from leisure noise would be welcome by a majority of the population. Recommendations are expected to be particularly welcome when it comes to protecting the hearing of young children and teenagers, as these vulnerable groups often do not have control over their environment and the noise levels to which they are exposed, such as from noisy toys or at school.

With resource use and implementation, the GDG noted that interventions exist to reduce exposure to leisure noise from PLDs, attendance at music venues and participation in recreational activities, as aggregated by the systematic review on environmental noise interventions and their associated impacts (Brown & van Kamp, 2017). As most of these relate to implementation of a behaviour change, the reduction of exposure to leisure noise is expected to be technically feasible and cheap. None of the empirical investigations objectively measured outcomes or a measured change in noise level exposure, so the effectiveness of such measures cannot be assessed. Nevertheless, it is important to note that there is ample evidence from the occupational health field that high noise levels cause hearing damage, and that occupational interventions to reduce noise exposure are effective at lowering the risk of hearing problems or hearing damage (EC, 2003; Garcia et al., 2018; ISO, 2013; Maassen et al., 2001). In conclusion, resources needed to reduce exposure to leisure noise are not expected to be intensive, but implementation and long-term success of measures might be challenging, owing to cultural factors, as changes in behaviour are expected to be tricky to implement.

In light of the assessment of the contextual factors in addition to the quality of evidence, the recommendation remains conditional.

Additional considerations or uncertainties

The GDG considers the noise levels selected for this recommendation to be reasonable precautionary measures, in view of the rating of very low quality for the available evidence on an effect of leisure noise on permanent hearing impairment and tinnitus identified in the systematic review.

Extensive literature shows hearing impairment in populations exposed to specific types of nonoccupational environments, although these exposures are generally not well characterized. There are no studies with objective measurement of exposure to any other type of leisure noise (except PLDs) and permanent hearing impairment or tinnitus. Nevertheless, this recommendation generally applies to all leisure noise exposures, such as events in public venues (concerts halls, sports events, bars and discotheques) and educational facilities, and use of PLDs. The recommendation also applies to exposure to impulse sounds, such as those in shooting facilities or from the use of toys and firecrackers.

Hearing loss is the resultant value of combined exposures to different sources of leisure noise including, but not limited to, PLDs. Therefore, the recommendations apply to the combined noise levels from all sources.

Noise-induced hearing loss develops very slowly over years of exposure, giving rise to challenges in the assessment of the health impacts from prolonged use of PLDs and exposure to leisure noise. The induction period for the development of hearing impairment and tinnitus is long, and varying

exposure conditions and changing lifestyle habits (including confounding noise sources), particularly among young people, will have an impact. Therefore, recommendations regarding leisure noise have often been inferred from the occupational field, where exposure conditions are more stable over time.

Indeed, long-term exposure to noise, objectively assessed and at levels measured in occupational settings for various professions, can lead to permanent hearing loss and tinnitus. This evidence, while not reviewed systematically as part of the work related to these guidelines, can be used as supportive evidence and justification for the need to develop a recommendation for leisure noise, given that many people could be at risk of developing hearing loss and/or tinnitus from exposure to lower levels of environmental noise. Similar otobiological mechanisms must also be considered for environmental noise.

To date, no commonly accepted method for assessing the risk of hearing loss due to environmental exposure to noise has been developed. One of the main challenges is to conduct a long-term objective exposure assessment of environmental noise and relate this to the development of permanent hearing impairment and tinnitus. The GDG underlined the strong need for research to develop a comprehensive methodology. In the absence of a method, and as long as no other tools are available, the equal energy principle outlined in the ISO standard for the estimation of noise-induced hearing loss (WHO, 1999) can be used as a practical tool for protecting public health from exposure to leisure noise. As a result, the relationship between leisure noise exposure and auditory effects can be quantified for a variety of exposure levels, duration and frequency.

Several organizations have established regulations for the protection of workers from risks to their health and safety arising from exposure to noise, and in particular risk to hearing. Of particular relevance is EU Directive 2003/10/EC on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (noise) (EC, 2003). Based on the ISO 1999 standard (ISO, 2013), the Directive sets limits of exposure depending on equivalent noise level for an eight-hour working day and obliges the employer to take suitable steps if the limits are exceeded. It recommends three action levels for occupational settings, setting the lowest, most conservative value at $L_{ex,8hr} = 80$ dB. According to the Directive, no consequences of exposure to occupational noise are expected at this level. While exposure patterns and certain characteristics of occupational and leisure noise exist, knowledge of the hearing impairment risks and preventive interventions can be used to assess health risks associated with leisure noise (Neitzel & Fligor, 2017).

The CNG recommend a limit of $L_{Aeq,24h} = 70$ dB(A) for preventing hearing loss from industrial, commercial shopping and traffic areas, indoors and outdoors (WHO, 1999). Health and safety regulations are usually based on an exposure profile of a typical worker (eight hours per day, five days per week). Using the existing knowledge from the ISO standard and established health and safety regulations, it is possible to use the equal energy principle to derive the resulting noise exposure level for an exposure profile more appropriately suited for leisure noise. Converting 40 hours at 80 dB to a continuous exposure to noise (24 hours per day, seven days per week), this leads to a yearly average exposure of 71 dB for lifelong exposure.²¹ This is the same value as the WHO recommendation of

²¹ 71 dB = 80 dB (derived from ISO standard) – 6.2 dB (conversion of yearly average of 40 working hours divided by continuous exposure to noise: $(10 \log (2080hrs/8760 hrs))$) – 3 dB (extrapolation of 40 working years to lifelong exposure).



70 dB (WHO, 1999). Table 49 presents the noise levels per hour for various time averages in order to keep within the recommended yearly average exposure, and assuming that exposure to other noise sources generally does not contribute significantly. For example, for specific events taking place for one-, two- or four-hour averages, once a week (such as visiting a discotheque or watching a loud movie), an hourly noise level of 85 dB would lead to an average yearly exposure of 63 dB, 66 dB and 69 dB, respectively. However, the same hourly exposure of 85 dB for an activity taking place for 14 hours per week (two hours per day, seven days a week) would lead to a yearly exposure of 74 dB, which exceeds the recommendations.

Table 49. Combination of hourly exposure and number of hours per week to arrive at a yearly average L_{Aeq}

Hours of exposure per week	One-hour exposure level (L_{Aeq})						
	70	75	80	85	90	95	100
1	48	53	58	63	68	73	78
2	51	56	61	66	71	76	81
4	54	59	64	69	74	79	84
14 (2 hours per day, 7 days per week)	59	64	69	74	79	84	89
28 (4 hours per day, 7 days per week)	62	67	72	77	82	87	92
40 (8 hours per day, 5 days per week)	64	69	74	79	84	89	94
168 (24 hours per day, 7 days per week)	70	75	80	85	90	95	100

Note: green = combinations of exposure/duration below current guideline level; red = combinations of exposure/duration above current guideline level; blue = input parameters.

The equal energy principle cannot be used to derive single-event limits because at high levels the ear starts to respond with nonlinear behaviour. The CNG provides several values, in different units: $L_{AF,max} = 110$ dB for industrial noises (no distance stated), $L_{peak,lin} = 140$ dB for adults and $L_{peak,lin} = 120$ dB for children (measured at 100 mm) (WHO, 1999). EU Directive 2003/10/EC on the minimum health and safety requirements regarding the exposure of workers recommends a lower action level of $L_{peak,C} = 135$ dB (at 100 mm). In a recent overview Hohmann (2015) provided an ERF for hearing damage caused by shooting noise, from which it appears that a safe level of $L_E = 120$ dB can be derived.

Although it is clear that high noise levels cause acute hearing damage, there is no agreement on a safe level. Further research is highly recommended. In the mean time, existing guidelines should be applied.

3.5.3 Summary of the assessment of the strength of recommendation

Table 50 provides a comprehensive summary of the different dimensions for the assessment of the strength of the leisure noise recommendations.

Table 50. Summary of the assessment of the strength of the recommendation

Factors influencing the strength of recommendation	Decision
Quality of evidence	Average exposure ($L_{Aeq,24h}$) <i>Health effects</i> - Evidence of an effect from PLDs on hearing impairment and tinnitus, in the absence of evidence for other health outcomes and absence of evidence on hearing impairment and tinnitus from other types of leisure noise besides PLDs, was rated very low quality. <i>Interventions</i> - No evidence was available on the effectiveness of interventions to reduce noise exposure and/or health outcomes from leisure noise.
Balance of benefits versus harms and burdens	The general benefit from reduction of leisure noise outweighs any potential harms.
Values and preferences	There is variability in the values and preferences of the general population.
Resource implications	The resources needed to reduce exposure to leisure noise are not expected to be intensive, but implementation and the long-term success of measures may be challenging, mainly due to cultural factors.
Decision on strength of recommendation	Conditional for guideline level for average noise exposure ($L_{Aeq,24h}$) Conditional for single-event and impulse noise Strong for interventions to reduce noise exposure

3.6 Interim targets

An interim target was proposed in the NNG (WHO Regional Office for Europe, 2009), “recommended in situations where the achievement of NNG is not feasible in the short run for various reasons”. The NNG emphasized that an interim target is “not a health-based limit value by itself. Vulnerable groups cannot be protected at this level”.

The GDG discussed whether to propose interim targets as part of the current guidelines, and if so, what process would be needed to derive those values. The current recommendations are health-based and already provide guideline values per noise source (for both L_{den} and L_{night}). They also include information on exposure–response relationships for various health outcomes, which can be used by policy-makers or other stakeholders to inform the selection of different values, if needed. Further, interim targets may work differently in different countries and for different noise sources, and it may not be optimal to propose them Europe-wide. As a result, there was consensus among members of the GDG not to provide interim targets.



4. Implications for research

The development of these environmental noise guidelines for the WHO European Region has made evident some key knowledge gaps and research needs. The main ones specific to the guideline recommendations are presented as implications for research in the sections that follow.

4.1 Implications for research on health impacts from transportation noise

For the assessment of health effects from the main sources of transportation noise (road traffic, railways and aircraft), the various evidence reviews show the following knowledge gap: there is a need for longitudinal studies on the health impacts from exposure to environmental noise, to inform future recommendations properly (Table 51).

Table 51. Implications for research on health impacts from transportation noise (air, rail, road)

Current state of the evidence	Limited evidence is available on health impacts from transportation noise from large-scale cohort and case-control studies, with objective measurement of both noise exposure and health outcomes.
Population of interest	Research is needed into effects of exposure on children and adults exposed to environmental noise from transportation sources.
Exposure of interest	Objective measurement or calculation of transportation noise exposure is required; in particular, from studies of health effects related to combined exposure to different noise sources.
Comparison of interest	The data should be compared to the effects of lower levels of transportation noise.
Outcomes of interest	Measures of the following health outcomes is required, assessed objectively and harmonized where possible – for example, according to common protocols: • annoyance • effects on sleep • cardiovascular and metabolic effects • adverse birth outcomes • cognitive impairment • mental health, quality of life and well-being • hearing impairment and tinnitus • any other relevant health outcome.
Time stamp	The systematic review included studies between October 2014 and December 2016.

4.1.1 Specific implications for annoyance

To predict absolute %HA at the full range of levels (and the corresponding CIs), an integrated analysis of the original raw data from all of individual studies would be necessary. The evidence review conducted as part of the guidelines focused only on secondary data handling and therefore does not replace a full meta-analysis of all individual data. The development of a generic exposure–response relationship (from a full meta-analysis based on all individual data) is suggested as a priority research recommendation (see Table 52).

Table 52. Recommendation for research addressing the exposure–response relationship

Current state of the evidence	The evidence review on annoyance conducted as part of the guidelines does not provide a generalized ERF but points to significant differences compared to the curves used in the past. It shows that the available generalized ERFs are in need of adjustment, preferably as a result of undertaking a full meta-analysis. This is especially the case for the sources aircraft and railway noise, which new data show are more annoying than previously documented.
Population of interest	Research is needed into effects of exposure on children and adults exposed to air, rail and/or road traffic noise.
Exposure of interest	Objective measurement of transportation noise exposure is required.
Comparison of interest	The data should be compared to the effects of lower levels of transportation noise.
Outcomes of interest	Measures of health outcomes are required, assessed objectively according to common protocols (such as the International Commission on Biological Effects of Noise (ICBEN) scale for annoyance).
Time stamp	The systematic review included studies up to October 2014.

4.2 Implications for research on health impacts from wind turbine noise

Further research into the health impacts from wind turbine noise is needed so that better-quality evidence can inform any future public health recommendations properly. For the assessment of health effects from wind turbines, the evidence was either unavailable or rated low/very low quality. Recommendations for research addressing this priority are proposed in Table 53.

Table 53. Implications for research on health impacts from wind turbine noise

Current state of the evidence	The current evidence on health outcomes related to wind turbine noise is unavailable or of low/very low quality and mainly comes from cross-sectional studies. Methodologically robust longitudinal studies with large samples investigating the quantitative relationship between noise from wind turbines and health effects are needed.
Population of interest	Research is needed into effects of exposure on children and adults exposed and living near sources of wind turbine noise. Studies should assess subgroup differences in effects for vulnerable groups such as children, elderly people and those with existing poor physical and mental health.
Exposure of interest	Exposure to noise at a wide range of levels and frequencies (including low-frequency noise), with information on noise levels measured outdoors and indoors (particularly relevant for effects on sleep) at the residence is needed. The noise exposure should be measured objectively and common protocols for exposure to wind turbine noise should be established, considering a variety of noise characteristics specific to wind turbine noise.
Comparison of interest	The data should be compared to the effects in similar areas without wind turbines. Pre/post studies of new wind turbine installations are needed, especially if “before measures” unbiased by the stress and knowledge of potential wind turbine farm development need to be developed.
Outcomes of interest	Measures of health outcomes are required, assessed objectively – for example, according to common protocols (ICBEN scale for annoyance and self-reported sleep disturbance). The studies should include the most important situational and personal confounding variables, such as negative attitudes towards wind turbines, visual impact, economic gain and other socioeconomic factors.
Time stamp	The systematic review included studies between October 2014 (review on annoyance) and December 2016 (review on cardiovascular disease).

Alongside the defined needs for research on wind turbine noise it should be noted that research regarding industrial noise in general is required. More specifically, there is a need to investigate stationary sources (including heat, ventilation and acclimatization devices) and their impacts on health. Studies on hearing disorders from impulse and/or intermittent sounds are also needed; these would enable assessment of adverse effects created by one or several sounds of short duration with a high maximum sound level or impulse sound level.

4.3 Implications for research on health impacts from leisure noise

For the assessment of effects from leisure noise, the evidence to make a recommendation on the ERF to use for health risk assessment, or of a threshold for effects, was either unavailable or rated very low quality. This is a research gap: longitudinal studies with longer follow-up are needed; these should measure noise objectively, not only from PLDs but also from other types of leisure noise.

There is uncertainty in the measurement of early hearing disorders among young people using the tonal audiometry commonly applied. Precise methods to identify early hearing impairment and other hearing disorders are needed. Owing to long induction periods, however, adequate research may be difficult to perform, particularly among young people who change their exposure in terms of sound level and frequency as they age (for example, changing their music listening habits and venue visits). As a result, the recommendations refer to the results derived from stationary noise sources in the occupational field, in conjunction with the equal energy principle (see Table 54).

Table 54. Implications for research on health impacts from leisure noise

Current state of the evidence	Currently, no evidence is available on hearing impairment and tinnitus from large-scale cohort and case-control studies, with objective measurement of noise exposure and using a suitable method to assess hearing impairment in young people.
Population of interest	Research is needed into effects of exposure on children and adults exposed to environmental noise from different sources and in different settings.
Exposure of interest	Objective measurement of leisure noise exposure is required.
Comparison of interest	The data should be compared to the effects of no leisure noise exposure from these sources.
Outcomes of interest	The primary outcomes identified are: • hearing loss measured by audiometry; • specific threshold analyses focused on stratifying the risk of permanent hearing loss according to clearly defined levels of exposure to leisure noise, such as music through PLDs; • concise methods to identify early hearing impairment and other hearing disorders; • temporary threshold shift after exposure to leisure noise, as it may be reasonably predictive of future permanent threshold shift; • age-related hearing loss progression depending on early-age exposure to leisure noise, such as to loud music; and • tinnitus, measured objectively and subjectively.
Time stamp	The systematic review included studies up to June 2015.

4.4 Implications for research on effectiveness of interventions to reduce exposure and/or improve public health

The quality of the evidence on the effectiveness of interventions to reduce exposure to and health outcomes from environmental noise was variable. Further studies directly linking noise interventions to health outcomes are required, particularly for sources other than road traffic noise, and for human health outcomes other than annoyance.

Most studies involved road traffic noise (63%), followed by aircraft noise (13%) and railway noise (6%). The remaining interventions were for leisure noise (13%) and noise in hospital settings (4%). No interventions were identified that either addressed wind turbine noise or focused on educational settings.

Exposure-related interventions were mainly associated with a reduction in environmental noise exposure. However, in five studies (four road traffic noise studies and one aircraft noise study) some or all of the participants experienced noise exposure increases.

There is no clear evidence with respect to thresholds, which are defined as:

- the smallest change in exposure levels that results in a change in outcome; and
- the minimum before-level, regarding changes in health outcomes as a result of interventions.

The limited evidence base on the health effects of environmental noise interventions is thinly spread across different noise source types, outcomes and intervention types. Diversity exists between studies even within intervention types in terms of study designs, methods of analysis, exposure levels and changes in exposure experienced as a result of the interventions. For these reasons, carrying out a meta-analysis across studies examining the association between changes in level and changes in outcome was not possible.

To remedy this main research gap, longitudinal studies assessing noise exposure and health outcomes objectively should be developed, taking into account the most relevant confounders. The establishment of common protocols for future research is warranted (see Table 55).

Authorities should include significant funding for the design and implementation of studies to evaluate the effectiveness of interventions to reduce noise and their impact on health.

Table 55. Implications for research on effectiveness of interventions to reduce exposure and/or improve public health

Current state of the evidence	The current evidence on effectiveness of interventions to reduce health outcomes is limited and of varying quality. Few longitudinal studies have been done that take into account the most relevant confounders and measure the noise exposure and the outcomes objectively.
Population of interest	Research is needed into effects of interventions on defined populations exposed to and/or living near sources of environmental noise.
Intervention of interest	Research into any noise intervention at various points along the system pathway between source and outcome, for a variety of noise sources, is required.
Comparison of interest	The data should be compared to: • a steady-state control group, in similar areas with various exposure gradients from environmental noise sources; • the noise exposure in the same population, through a series of sequential measurements assessing the change before and after the intervention, preferably with multiple after measurements.
Outcomes of interest	Future intervention studies should use validated and, where possible, harmonized measures of exposure and outcome, as well as of moderators and confounders. The studies should use measures of exposure including noise exposure at a wide range of levels and frequencies (including low-frequency noise), with information on noise levels outdoors and indoors (particularly relevant for effects on sleep). They should also use measures of health outcomes, including the following outcomes assessed objectively – for example, according to common protocols (ICBEN scale for annoyance) – with consideration that the change in human response for some health outcomes from a step change in exposure may have a different time course to that of the change in exposure: • annoyance • effects on sleep • cardiovascular and metabolic diseases • adverse birth outcomes • cognitive impairment • mental health, quality of life and well-being • hearing impairment and tinnitus • any other relevant health outcome. Further, they should use measures of moderators and confounders, including repeated measurements of situational and personal variables such as activity interference, potential confounders such as noise sensitivity, coping strategies and a range of other attitudinal variables.
Time stamp	The systematic review included studies up to October 2014.

5. Implementation of the guidelines

5.1 Introduction

These guidelines focus on the WHO European Region and provide guidance to Member States that is compatible with the noise indicators used in the EU's END (EC, 2002a). They provide information on the exposure–response relationships between exposure to environmental noise from different noise sources and the proportion of people affected by certain health outcomes, as well as interventions that are considered efficient in reducing exposure to environmental noise and related health outcomes.

The WHO guideline values are evidence-based public health-oriented recommendations. As such, they are recommended to serve as the basis for a policy-making process in which policy options are considered. In the policy decisions on reference values, such as noise limits for a possible standard or legislation, additional considerations – such as feasibility, costs, preferences and so on – feature in and can influence the ultimate value chosen as a noise limit. WHO acknowledges that implementing the guideline recommendations will require coordinated effort from ministries, public and private sectors and nongovernmental organizations, as well as possible input from international development and finance organizations. WHO will work with Member States and support the implementation process through its regional and country offices.

5.2 Guiding principles

Four guiding principles provide generic advice and support when incorporating the recommendations into a policy framework, and apply to the implementation of all the recommendations.

The **first principle** is to reduce exposure to noise, while conserving quiet areas. The recommendations focus on reduction of population exposure to environmental noise from a variety of sources, in different settings. The general population can be exposed regularly to more than one source of noise simultaneously (including, in some cases, occupational noise), as well as to other nonacoustic factors that can modify the response to noise (such as vibration from railways, air pollution from traffic or visual aspects of wind turbines). Thus, overall reduction of exposure from all sources should be promoted. Furthermore, noise exposure reduction in one area should not come at the expense of an increase in noise elsewhere; existing large quiet outdoor areas should be preserved.

The **second principle** is to promote interventions to reduce exposure to noise and improve health. The evidence from epidemiological studies on adverse health effects at certain noise levels, used as a basis to derive the guideline values proposed in the recommendations, supports the promotion of noise interventions. The potential health impacts from environmental noise are significant, especially when considering the widespread exposure to environmental noise across the population and the high baseline rates for various health outcomes associated with environmental noise.

There are challenges in assessment of the effectiveness of interventions to reduce noise exposure and/or improve health, as there is often a significant time lag between the intervention and a measurable change in exposure and related health benefits. The lack of – or limited direct evidence

for – quantifiable health benefits of some specific interventions does not imply that measures to achieve population exposure according to the proposed guidelines should be ignored.

Given the different factors that determine noise exposure, a single measure alone may not be sufficient to reduce exposure and/or improve health significantly, and a combination of methods may be warranted. Nevertheless, it is widely acknowledged that the most effective actions to reduce exposure tend to be those that reduce noise at the source. Such actions have the biggest potential, whereas other measures can be less effective or sustained over time, especially when they depend on behaviour change or noise reductions inside houses.

The **third principle** is to coordinate approaches to control noise sources and other environmental health risks. Considering the common transport-related sources of environmental noise and air pollution, and in particular the evidence of independent effects on the cardiovascular system, a coordinated approach to policy development in the sectors related to urban planning, transport, climate and energy should be adopted for policies with an impact on environmental noise, air quality and/or climate. Such an approach should yield multiple benefits through increased commitment and financial resources; increased attention to securing health considerations in all policies; and use of policy to control noise and other environmental risks such as air pollutants, including short-lived climate pollutants. There is wide consensus on the value of pursuing coordinated policies that can deliver health and other benefits, such as those associated with the local environment and economic development. Furthermore, coordinated policy-making is potentially cost-saving.

The **fourth principle** is to inform and involve communities that may be affected by a change in noise exposure. In planning new urban and/or rural developments (transport schemes, new infrastructures in less densely populated areas, noise abatement and mitigation strategies), bringing together planners, environmental professionals and public health experts with policy-makers and citizens is key to public acceptability and involvement and to the successful guidance of the decision-making process. Potential health effects from environmental noise should be included as part of health impact assessments of future policies, plans and projects, and the communities potentially affected by a positive or negative change in noise exposure should be well informed and engaged from the outset to maximize potential benefits to health. Introducing measures incrementally may help with acceptance.

5.3 Assessment of national needs and capacity-building

National needs, including the need for capacity-building, differ between Member States in the WHO European Region. They depend on the existence and level of implementation of national and/or European and international noise policies; these are more likely to be implemented fully in EU countries thanks to the legally binding provisions of the EU's END (EC, 2002a). In most countries in the Region noise is perceived as a major and growing environmental health and public health problem. Noise mapping and action plans are carried out in accordance with the END in EU Member States, and in south-eastern European countries noise legislation has mainly been harmonized with the END. Nevertheless, significant differences still exist in the completeness and regular updating of noise exposure assessment between countries. Noise exposure assessment is a required input for noise health impact assessments, along with exposure-response relationships and population baseline data.

WHO has identified some common needs for knowledge transfer and capacity-building for health risk assessment of environment noise in the Member States that joined the EU after 2003, the newly independent states and south-eastern European countries (WHO Regional Office for Europe, 2012):

- implementation of the END and its annexes, especially in the preparation of strategic noise mapping and action plans;
- human resources development through education and training in health risk assessment and burden of diseases stemming from environmental noise;
- methodological guidance for health risk assessment of environmental noise.

These guidelines mostly recommend exposure–response relationships related to the exposure indicators L_{den} and L_{night} . They are therefore of particular relevance to EU countries and those applying the END. In countries that do not use these indicators, users of the guidelines need to convert their noise indicators into L_{den} and L_{night} before being able to apply the recommendations. Conversion between indicators is possible, using a certain set of assumptions (Brink et al., 2018).

5.4 Usefulness of guidelines for target audiences

The provision of guideline values as a practical tool for guiding exposure reduction and the design of effective measures and policies is widely seen as useful. The WHO guidelines equip policy-makers and other end-users with a range of different needs with the necessary evidence base to inform their decisions. As indicated in section 1.4, these guidelines serve as a reference for several target audiences, and for each group they can be useful in different ways.

- For technical experts and decision-makers, the guidelines can be used to provide exposure–response relationships that give insight into the consequences of certain regulations or standards on the associated health effects. They also can be useful at the national and international level when developing noise limits or standards, as they provide the scientific basis to identify the levels at which environmental noise causes a significant health impact. Based on these recommendations, national governments and international organizations can be better informed when introducing noise limits, to ensure protection of people's health.
- For health impact assessment and environmental impact assessment practitioners and researchers, these guidelines provide exposure–response relationships that give insight into the expected health effects at observed or expected noise exposure levels. They offer recommendations on the maximum admissible noise levels for some sources and provide important input to assist in deriving the health burden from noise; in that sense, they can be used when producing studies such as noise maps and action plans to obtain an evaluation of the magnitude of the health problem. The systematic reviews developed in support of these guidelines allow practitioners to raise awareness of the credibility of the issue of noise as a public health problem and to use the recommended exposure–response relationships uniformly. Researchers will also benefit from the guidelines as they clearly identify critical data gaps that need to be filled in the future to better protect the population from the harmful effects of noise.
- The guideline recommendations provide a useful tool for national and local authorities when deciding about noise reduction measures, as they provide data to estimate the health burden on the population and therefore allow comparison among different policy options. These options

can include measures to reduce the noise emitted by the sources, measures aimed at impeding the transmission of noise from the sources to people and measures aimed at better planning the location of houses (urban planning).

- The guideline recommendations can also be used by civil society, patients and other advocacy groups to raise awareness and encourage actions to protect the population, including vulnerable groups, from exposure to noise.

Regarding noise abatement and mitigation of noise sources, practical exposure–response relationships for various noise sources are useful quantitative input to determine the impact of noise on health. They can be valuable information to use in cost–effectiveness and cost–benefit analyses of various policies for noise abatement. In this respect, the guideline recommendations can be an integral part of the policy process for noise reduction by various institutions; they are of great value for communicating the health risks and potential cost-effective solutions to reduce noise.

National and local authorities and nongovernmental organizations responsible for risk communication and general awareness-raising can use these guidelines for promotion campaigns and appropriate risk communication. The guidelines provide scientific evidence on a range of health effects associated with noise and facilitate appropriate risk communication to specific vulnerable groups. They therefore need to be promoted broadly to citizens, national and local authorities and nongovernmental organizations responsible for risk communication.

5.5 Methodological guidance for health risk assessment of environmental noise

A health risk assessment is the scientific evaluation of potential adverse health effects resulting from human exposure to a particular hazard – in this case, environmental noise. The main purpose of the assessment is to estimate and communicate the health impact of exposure to noise or changes in noise in different socioeconomic, environmental and policy circumstances.

The guideline recommendations, along with the detailed information contained in the systematic evidence reviews, can be used to assess health impacts in order to answer a variety of policy questions on:

- the public health burden associated with current or projected levels of noise;
- the human health benefits associated with changing a noise policy or applying a more stringent noise standard;
- the impacts on human health of emissions from specific sources of noise for selected economic sectors (and the benefits of policies related to them); and
- the human health impacts of current policy or implemented action.

The results from a health risk assessment are usually reported as the number of attributable deaths, number of cases, years of life lost, years lost due to disability or DALYs.

The quantification of the impacts for one combination of noise source, noise exposure indicator and health outcome may to some extent include effects attributable to another. Consequently, for any particular set of combinations, consideration should be given to potential double counting.

It is also important to note the uncertainties in quantification of the health impacts. One set of uncertainties relates to the CIs associated with the recommended ERFs; these quantify the random

error and variability attributed to heterogeneity in the epidemiological studies used for health risk assessment. Other types of uncertainty include modelling/calculation of noise exposure, estimates of population background rates for morbidity and mortality, and transferability of ERFs from locations where studies were carried out or data were otherwise gathered to another location. This is especially true for noise annoyance, for which there is often considerable heterogeneity in effect sizes of studies because estimates vary between noise sources and are to some degree dependent on the situation and context. Furthermore, cultural differences around what is considered annoying are significant, even within Europe. It is therefore not possible to determine the “exact value” of %HA for each exposure level in any generalized situation. Instead, data and exposure–response curves derived in a local context should be applied whenever possible to assess the specific relationship between noise and annoyance in a given situation. If, however, local data are not available, general exposure–response relationships can be applied, assuming that the local annoyance follows the generalized average annoyance. Despite the challenges in applying a “generalized” ERF to specific local situations, the GDG believes that the percentage of high annoyance defined in section 2.4.3 is an acceptable estimate of the “average” %HA at a certain noise level – for example, in Europe.

When performing a health risk assessment of environmental noise, it is important to note several considerations. The selection of particular noise source(s), noise exposure indicator(s) and health outcome combinations to be used for estimation of the health impacts depends on the particular policies and/or measures being assessed. These guidelines propose recommendations for four types of noise source using noise indicators L_{den} and/or L_{night} (road traffic, railway noise, aircraft noise and wind turbine noise) and one recommendation using $L_{Aeq,24h}$ (leisure noise). Any population may be exposed to different noise sources associated with the same health outcome. Estimated impacts should not be added together without recognizing that addition will, in most practical circumstances, lead to some overestimation of the true impact. Impacts estimated for only one combination will, on the other hand, underestimate the true impact of the noise mixture, if other sources of noise also affect that same health outcome.

The scientific evidence reviewed and summarized in these guidelines implies that the following health outcomes can be quantified in a health risk assessment, and that their effects are cumulative:

- from road traffic noise – incidence of IHD, annoyance and sleep disturbance, and potentially incidence of stroke and diabetes;
- from railway noise – annoyance and sleep disturbance;
- from aircraft noise – annoyance, reading and oral comprehension in children, sleep disturbance and potentially change in waist circumference and incidence of IHD;
- from wind turbine noise: annoyance.

The DWs suggested in section 2.4.3 can be used to calculate DALYs.

Data on incidence and prevalence of some health outcomes related to noise (mainly cardiovascular disease) can be found at a national level in online databases available on the WHO Regional Office for Europe website (WHO Regional Office for Europe, 2017).

General principles of relevance for environmental factors when conducting health risk assessments and quantifying the burden of disease can be found elsewhere (European Centre for Health Policy, 1999; Murray, 1994; Murray & Acharya, 1997; Murray & Lopez, 2013; Quigley et al., 2006; WHO,

2014a; 2014b; WHO Regional Office for Europe, 2016). In particular, the WHO Regional Office for Europe and JRC jointly published the first estimates of the burden of disease from environmental noise in 2011 (WHO Regional Office for Europe & JRC, 2011). The publication includes guidance on the procedure for the health risk assessment of environmental noise, exemplary estimates of the burden of the health impacts of environmental noise and a discussion of the uncertainties and limitations of the procedure to calculate the environmental burden of disease. The reader is referred to this publication for more detailed explanations on quantitative risk assessment methods for environmental noise.

5.6 Route to implementation: policy, collaboration and the role of the health sector

Preventing noise and related health impacts relies on effective action across different sectors: health, environment, transport, urban planning and so on. The health sector needs to be engaged effectively in different sectors' policy processes at national, regional and international levels. It needs to provide authoritative advice about the health impacts of noise and policy options that will bring the greatest benefits to health.

In most countries in the WHO European Region, the commitment of the health sector to engage in action to address environmental noise issues needs to be improved and better coordinated. A more coherent overall response is needed, taking into account relevant linkages with existing health priorities and concerns. Thus, some actions can be seen as aspects of the role of the health sector:

- engaging in proper communication with relevant sectors about noise exposure from different sectors and sources (environmental, urban development, transport and so on) to ensure that health issues are adequately addressed as part of international, regional, national and/or local efforts to address environmental noise – the implementation approach may differ across sectors, depending on the level of awareness of noise as a public health problem;
- promoting the guideline recommendations to policy-makers from different sectors and organizing information campaigns and awareness-raising activities in collaboration with national health authorities and WHO country offices to inform citizens and health practitioners about the health risks of environmental noise;
- using decision support instruments such as health impact and health risk assessments to quantify health risks and potential benefits associated with policies and interventions aimed at addressing environmental noise, including presenting information about the severity of the health effects (for example, with cardiovascular disease) to convey the serious impacts of noise and to try to change attitudes and behaviours of policy-makers and the general public;
- promoting the guidelines to health practitioners and physicians, especially at the community level (through associations of physicians, cardiologists and so on as part of the stakeholder group);
- supporting the establishment of national health institutions capable of initiating and developing health promotion measures, and conducting research, monitoring and reporting on health impacts from environmental noise and its different sources;

- organizing capacity-building workshops and training to increase knowledge of the guidelines as well as creating tools, skills and resources for health risk assessment and developing intersectoral collaboration, particularly in non-EU countries;
- promoting relevant research initiatives and shaping the research agenda, in part based on critical research recommendations and gaps identified in the guidelines, as well as on the impact and effectiveness of interventions and experience with their implementation;
- developing and updating guidelines and policies that influence national, regional and international benchmarks and targets related to environmental noise, as well as advocating the inclusion of the guidelines in development and shaping of national, regional and international noise policies and standards;
- working with other sectors to strengthen noise level monitoring and evaluation, particularly in non-EU countries, to ensure proper conducting of health risk assessments of environmental noise.

5.7 Monitoring and evaluation: assessing the impact of the guidelines

Exposure–response relationships and other recommendations provided by these guidelines should be incorporated into national health policies and the main related policy documents. They should be used for health impact and health risk assessments to identify health risks and potential benefits associated with policies and interventions related to environmental noise.

Population noise exposure should be monitored and assessed at a national scale, at least in urban areas. Furthermore, information on trends in occurrence of noise-related health outcomes considered in these guidelines, such as annoyance or sleep disturbance, should be gathered. These monitoring activities should be performed on a regular basis to ensure proper health risk assessments of noise.

5.8 Updating the guidelines

The progress and pace of noise and health research has intensified over the last 10 years, including new studies published after the completion of the systematic reviews done for these guidelines. This is partly related to the growing car fleet and resulting traffic, the density of urbanization, demographic changes and shifts towards renewable energy, including wind turbines, which have caused an increase in public perception and political awareness of the environmental noise problem. Noise exposure assessment has also improved, due partly to European legislation, and this has provided useful data for epidemiological studies on the health effects of environmental noise. Considering this, the recommendations proposed in these guidelines are expected to remain valid for a period of about 10 years. WHO will monitor the development of the scientific advancements on noise and health research in order to inform any updated guidance on environmental noise.

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Annexes

Annex 1. Steering, advisory and external review groups

Tables A1.1–A1.5 give details of the various teams involved in the development of the WHO environmental noise guidelines for the European Region.

Table A1.1 WHO Steering Group

Name	Role	Affiliation
Shelly Chadha	Technical Officer, Office for Hearing Impairment	WHO headquarters, Geneva, Switzerland
Carlos Dora	Coordinator	WHO headquarters, Department of Public Health and Environment, Geneva, Switzerland
Marie-Eve Héroux	Technical Officer, Air Quality and Noise	WHO Regional Office for Europe, European Centre for Environment and Health, Bonn, Germany
Dorota Jarosinska	Programme Manager, Living and Working Environments	WHO Regional Office for Europe, European Centre for Environment and Health, Bonn, Germany
Rokho Kim	Environmental Health Specialist, Team Leader	WHO Regional Office for the Western Pacific, Division of Noncommunicable Diseases and Health through the Life-Course, Manila, Philippines
Jurgita Lekaviciute	Consultant, Noise	WHO Regional Office for Europe, European Centre for Environment and Health, Bonn, Germany
Srdan Matic	Coordinator, Environment and Health	WHO Regional Office for Europe, Copenhagen, Denmark
Julia Nowacki	Technical Officer, Health Impact Assessment	WHO Regional Office for Europe, European Centre for Environment and Health, Bonn, Germany
Elizabet Paunovic	Head of Office	WHO Regional Office for Europe, European Centre for Environment and Health, Bonn, Germany
Poonum Wilkhu	Consultant, Noise	WHO Regional Office for Europe, European Centre for Environment and Health, Bonn, Germany
Jördis Wothge	Consultant, Noise	WHO Regional Office for Europe, European Centre for Environment and Health, Bonn, Germany

Table A1.2. Guideline Development Group

Area of expertise		Reference	Area of expertise								Reference
Noise sources and their measurement		1	Annoyance								6
Biological mechanisms of effects		2	Cognitive impairment, quality of life, mental health and well-being								7
Cardiovascular and metabolic diseases		3	Adverse birth outcomes								8
Sleep disturbance		4	Environmental noise interventions								9
Hearing impairment/tinnitus		5	Methodology and guideline development								10
Name	Position and affiliation	Area of expertise sought for guideline development (see reference numbers above)									
		1	2	3	4	5	6	7	8	9	10
Wolfgang Babisch	Senior Scientific Officer (retired) Federal Environment Agency Germany		X	X		X					
Goran Belojevic	Professor Institute of Hygiene and Medical Ecology Faculty of Medicine University of Belgrade Serbia			X			X				
Mark Brink	Senior Scientist Federal Office for the Environment Switzerland	X			X		X				
Sabine Janssen	Senior Scientist Department of Sustainable Urban Mobility and Safety Netherlands Organisation for Applied Scientific Research (TNO) Netherlands				X		X				
Peter Lercher (2013–2014)	Professor Medical University of Innsbruck Austria							X	X		
Marco Paviotti	Policy Officer Directorate-General for Environment European Commission Belgium	X								X	
Göran Pershagen	Professor Institute of Environmental Medicine Karolinska Institute Sweden		X	X					X		



Table A1.2. contd

Area of expertise		Reference	Area of expertise								Reference
Noise sources and their measurement		1	Annoyance								6
Biological mechanisms of effects		2	Cognitive impairment, quality of life, mental health and well-being								7
Cardiovascular and metabolic diseases		3	Adverse birth outcomes								8
Sleep disturbance		4	Environmental noise interventions								9
Hearing impairment/tinnitus		5	Methodology and guideline development								10
Name	Position and affiliation	Area of expertise sought for guideline development (see reference numbers above)									
		1	2	3	4	5	6	7	8	9	10
Kerstin Persson Waye	Professor Occupational and Environmental Medicine The Sahlgrenska Academy University of Gothenburg Sweden	X			X		X				
Anna Preis	Professor Institute of Acoustics Adam Michiewicz University Poland					X	X				
Stephen Stansfeld (Chair)	Professor/Head of the Centre for Psychiatry Barts and Queen Mary University of London United Kingdom							X			
Martin van den Berg	Senior Noise Expert Ministry of Infrastructure and Environment Netherlands	X									
GRADE methodologist											
Jos Verbeek	Senior Researcher Finnish Institute of Occupational Health Finland	X									

Table A1.3. Systematic Review Team

Systematic review topics	Experts involved	Affiliation
Cardiovascular and metabolic diseases	Elise van Kempen	National Institute of Public Health and the Environment (RIVM), Netherlands
	Göran Pershagen	Institute of Environmental Medicine, Karolinska Institute, Sweden
	Maribel Casas Sanahuja	Institute for Global Health (ISGlobal), Spain
	Maria Foraster	Barcelona Institute for Global Health (ISGlobal), Spain and Swiss Tropical and Public Health Institute, Switzerland
Sleep disturbance	Mathias Basner	Department of Psychiatry, Perelman School of Medicine at the University of Pennsylvania, United States of America
	Sarah McGuire	Department of Psychiatry, Perelman School of Medicine at the University of Pennsylvania, United States of America
Hearing impairment and tinnitus	Mariola Sliwinska-Kowalska	Nofer Institute of Occupational Medicine, Poland
	Kamil Rafal Zaborowski	Nofer Institute of Occupational Medicine, Poland
Annoyance	Rainer Guski	Department of Psychology, Ruhr-University, Germany
	Dirk Schreckenberg	ZEUS GmbH, Centre for Applied Psychology, Environmental and Social Research, Germany
	Rudolf Schuemer	Consultant for ZEUS GmbH, Centre for Applied Psychology, Environmental and Social Research, Germany
Cognitive impairment, mental health and well-being	Charlotte Clark	Ove Arup & Partners, United Kingdom
	Katarina Paunovic	Institute of Hygiene and Medical Ecology, Faculty of Medicine, University of Belgrade, Serbia
Adverse birth outcomes	Mark Nieuwenhuijsen	Institute for Global Health (ISGlobal), Spain
	Gordana Ristovska	Institute of Public Health of Republic of Macedonia, the former Yugoslav Republic of Macedonia
	Payam Dadvand	Institute for Global Health (ISGlobal), Spain
Interventions	Lex Brown	Griffith School of Environment/Urban Research Program, Griffith University, Australia
	Irene Van Kamp	National Institute of Public Health and the Environment (RIVM), Netherlands

Table A1.4. External Review Group

Area of expertise		Reference	Area of expertise		Reference
Cardiovascular and metabolic diseases		1	Cognitive impairment, mental health and well-being		5
Sleep disturbance		2	Adverse birth outcomes		6
Hearing impairment/ Tinnitus		3	Environmental noise interventions		7
Annoyance		4	Recommendations and implementation guidance		8

Name	Affiliation	Area of expertise sought for guideline development (see reference numbers above)							
		1	2	3	4	5	6	7	8
Gunn Marit Aasvang	Norwegian Institute of Public Health, Norway		X						
Bernard Berry	Berry Environmental Limited, United Kingdom							X	
Dick Botteldooren	Department of Information Technology, Ghent University, Belgium				X				
Stephen Conaty	South Western Sydney Local Health District, Australia								X
Ulrike Gehring	Institute for Risk Assessment Sciences, Utrecht University, Netherlands						X		
Truls Gjestland	SINTEF, Department of Acoustics, Norway				X				
Mireille Guay	Healthy Environments and Consumer Safety Branch, Health Canada/Government of Canada, Canada		X		X				
Ayşe Güven	Audiology Department, Faculty of Health Sciences, Baskent University, Turkey			X					
Anna Hansell	Centre for Environmental Health & Sustainability, George Davies Centre, University of Leicester, United Kingdom	X							X
Stilianos Kephelopoulou	European Commission, DG Joint Research Centre, Italy							X	X
Yvonne de Kluizenaar	The Netherlands Organization for applied scientific research (TNO), Netherlands							X	
David S. Michaud	Healthy Environments and Consumer Safety Branch, Health Canada/Government of Canada, Canada		X		X				
Arnaud Norena	Université Aix-Marseille, Fédération de Recherche, Laboratoire Cognitive Neuroscience, France			X					
Enembe Okokon	National Institute for Health and Welfare, Finland								X
Dieter Schwela	Stockholm Environment Institute, University of York, United Kingdom								X
Daniel Shepherd	AUT University, Auckland, New Zealand					X			
Mette Sørensen	Danish Cancer Society Research Centre, Denmark	X							X
Rupert Thornley-Taylor	Rupert Taylor Ltd, Noise and Vibration Consultants							X	X
David Welch	School of Population Health, Faculty of Medical and Health Sciences, University of Auckland, New Zealand			X				X	

Table A1.5. Stakeholders and end users that participated in the stakeholder consultation

Area of expertise/interest	Reference	Area of expertise	Reference
Implementation of recommendations on railway noise	1	Implementation of recommendations on wind turbine noise	4
Implementation of recommendations on aircraft noise	2	Implementation of recommendations on leisure noise	5
Implementation of recommendations on road traffic noise	3	Implementation of overall recommendations	6

Organization	Area of expertise specifically sought for Guidelines (see reference number above)					
	1	2	3	4	5	6
Airlines for Europe		X				
Airports Council International Europe (ACI)		X				
Anderson Acoustics		X				
Bundesverband der Deutschen Luftverkehrswirtschaft e.V.		X				
European Automobile Manufacturers' Association (ACEA)			X			
European Aviation Safety Agency		X				
European Express Association	X					
European Noise Barrier Federation						X
Flughafenverband (ADV)		X				
International Air Transport Association (IATA)		X				
International Civil Aviation Organization (ICAO)		X				
International Union of Railways	X					
Landesamt fuer Natur, Umwelt und Verbraucherschutz Nordrhein-Westfalen						X
Public Health Agency of Sweden						X
Stephen Turner Acoustics					X	X
Union Européenne Contre les Nuisances Aeriennes		X				
Vie en.ro.se.						X

Note: in total 53 organizations and institutions had been approached to participate in the stakeholder consultation.

Annex 2. Systematic reviews and background documents used in preparation of the guidelines

Annex 2 provides a detailed list of all the supplementary documents accompanying the WHO environmental noise guidelines for the European Region.²²

Systematic reviews

- Basner M, McGuire S (2018). WHO environmental noise guidelines for the European Region: a systematic review on environmental noise and effects on sleep. *Int J Environ Res Public Health*. 15(3);pii: E519 (<http://www.mdpi.com/1660-4601/15/3/519/htm>).
- Brown AL, van Kamp I (2017). WHO environmental noise guidelines for the European Region: a systematic review of transport noise interventions and their impacts on health. *Int J Environ Res Public Health*. 14(8). pii: E873 (<http://www.mdpi.com/1660-4601/14/8/873/htm>).
- Clark C, Paunovic K (2018). WHO environmental noise guidelines for the European Region: a systematic review on environmental noise and cognition. *Int J Environ Res Public Health*. 15(2). pii: E285 (<http://www.mdpi.com/1660-4601/15/2/285/htm>).
- Clark C, Paunovic K (in press). WHO Environmental noise guidelines for the European Region: a systematic review on environmental noise and quality of life, wellbeing and mental health. *Int J Environ Res Public Health*.
- Guski R, Schreckenber D, Schuemer R (2017). WHO environmental noise guidelines for the European Region: a systematic review on environmental noise and annoyance. *Int J Environ Res Public Health*. 14(12). pii: 1539 (<http://www.mdpi.com/1660-4601/14/12/1539/htm>).
- Nieuwenhuijsen MJ, Ristovska G, Dadvand P (2017). WHO environmental noise guidelines for the European Region: a systematic review on environmental noise and adverse birth outcomes. *Int J Environ Res Public Health*. 14(10). pii: E1252 (<http://www.mdpi.com/1660-4601/14/10/1252/htm>).
- Śliwińska-Kowalska M, Zaborowski K (2017). WHO environmental noise guidelines for the European Region: a systematic review on environmental noise and permanent hearing loss and tinnitus. *Int J Environ Res Public Health*. 14(10). pii: E1139 (<http://www.mdpi.com/1660-4601/14/10/1139/htm>).
- van Kempen E, Casas M, Pershagen G, Foraster M (2018). WHO environmental noise guidelines for the European Region: a systematic review on environmental noise and cardiovascular and metabolic effects: a summary. *Int J Environ Res Public Health*. 15(2). pii: E379 (<http://www.mdpi.com/1660-4601/15/2/379/htm>).

²² All references were accessed on 27 June 2018.

Background documents

- Eriksson C, Pershagen G, Nilsson M (2018). Biological mechanisms related to cardiovascular and metabolic effects by environmental noise. Copenhagen: WHO Regional Office for Europe (<http://www.euro.who.int/en/health-topics/environment-and-health/noise/publications/2018/biological-mechanisms-related-to-cardiovascular-and-metabolic-effects-by-environmental-noise>).
- Héroux ME, Verbeek J (2018a). Results from the search for available systematic reviews and meta-analyses on environmental noise. Copenhagen: WHO Regional Office for Europe (<http://www.euro.who.int/en/health-topics/environment-and-health/noise/publications/2018/results-search-for-available-systematic-reviews-environmental-noise>).
- Héroux ME, Verbeek J (2018b). Methodology for systematic evidence reviews for the WHO environmental noise guidelines for the European Region. Copenhagen: WHO Regional Office for Europe (<http://www.euro.who.int/en/health-topics/environment-and-health/noise/publications/2018/methodology-systematic-evidence-reviews-who-environmental-guidelines-for-the-european-region>).

Annex 3. Summary of conflict of interest management

All external contributors to the guidelines, including members of the GDG, Systematic Review Team and External Review Group, completed WHO declaration of interest forms in accordance with WHO's policy for experts. Further, at the initial stage of the project WHO technical staff reviewed and accepted *curricula vitae* of the candidates for the GDG.

At the beginning of the GDG meetings, the participants declared any conflict of interest by submitting declaration of interest forms. Updated declarations of interest were also collected from the members of the GDG, Systematic Review Team and External Review Group at the final stage of the project.

The conflict of interest assessment was done according to WHO procedures. If a conflict was declared, an initial review was undertaken by the WHO Secretariat to assess its relevance and significance. A declared conflict of interest is insignificant or minimal if it is unlikely to affect or to be reasonably perceived to affect the expert's judgment. Insignificant or minimal interests are: unrelated or only tangentially related to the subject of the activity or work and its outcome; nominal in amount or inconsequential in importance; or expired and unlikely to affect current behaviour.

The WHO Secretariat reviewed and assessed the declarations. In one case the legal unit was consulted for advice; in another the potential conflict was reported in the updated declaration of interest at the final stage of the process and assessed unlikely to affect expert's performance; in a further case a member of the GDG was also a co-author of a systematic review owing to the need to support systematic review authors with additional expertise, but there was no remuneration for this activity.

No member of the GDG or the Systematic Review Team was excluded from his or her role in the guideline development process. The declared conflicts of interest of the External Review Group members were considered when interpreting comments during the external review process.

Annex 4. Detailed overview of the evidence of important health outcomes

As a first step of the evidence retrieval process, the GDG defined two categories of health outcome associated with environmental noise: those considered (i) critical or (ii) important, but not critical for decision-making in the guideline development process.

The GDG relied on the critical health outcomes to inform its decisions on priority health outcomes, so only these were used to inform the recommendations. Nevertheless, as the relevance of some of important health outcomes was difficult to estimate *a priori*, systematic reviews were conducted for both critical and important health outcomes.

This annex provides a detailed overview of the evidence of the important health outcomes – namely adverse birth outcomes, quality of life, well-being and mental health and metabolic outcomes – for each of the noise sources. A comprehensive discussion of all the evidence considered (both critical and important) is available in the published systematic reviews (see section 2.3.2 and Annex 2 for details).

1. Road traffic noise

1.1 Adverse birth outcomes

In total, the systematic review found five studies (two with more or less the same population) on road traffic noise and birth outcomes and three related studies on total ambient noise, likely to be mostly road traffic noise. Too few studies for each of the various measures related to adverse birth outcomes were available to undertake a quantitative meta-analysis. There was evidence rated low quality for a relationship between road traffic noise and low birth weight (Dadvand et al., 2014; Gehring et al., 2014; Hjortebjerg et al., 2016; Wu et al., 1996); however, the estimates were imprecise and in some cases not statistically significant. Further, there was no clear relation between exposure to road traffic noise and pre-term delivery, but there was a positive association between road traffic noise and small for gestational age (OR = 1.09; 95% CI: 1.06–1.12 per 6 dB increase). The evidence for both measures of adverse birth outcomes comes from the same publications and this evidence was rated low quality (Gehring et al., 2014; Hystad et al., 2014).

This evidence was supported by one ecological time-series study published recently looking at total ambient noise and various measures related to adverse birth outcomes (Arroyo et al., 2016a; 2016b; Diaz et al., 2016).

1.2 Quality of life, well-being and mental health

Evidence rated moderate quality was found for an effect of road traffic noise on emotional and conduct disorders in childhood (Belojevic et al., 2012; Crombie et al., 2011; Hjortebjerg et al., 2015; Ristovska et al., 2004; Stansfeld et al., 2005; 2009a; Tiesler et al., 2013) and evidence rated moderate quality for an association of road traffic noise with hyperactivity in children (Hjortebjerg et al., 2015; Tiesler et al., 2013).

There was no clear relationship, however, between road traffic noise exposure and self-reported quality of life (evidence rated low quality) (Barcelo Perez & Piñeiro, 2008; Brink, 2011; Clark et al., 2012; Honold et al., 2012; Roswall et al., 2015; Schreckenbergen et al., 2010b; Stansfeld et al., 2005; 2009b; van Kempen et al., 2010); medication intake for depression and anxiety (evidence rated very low quality) (Floud et al., 2011; Halonen et al., 2014); depression, anxiety and psychological distress (evidence rated very low quality) (Honold et al., 2012; Stansfeld et al., 2009b); and interview measures of depression and anxiety (evidence rated very low quality) (Stansfeld et al., 2009b).

1.3 Metabolic outcomes

1.3.1 Diabetes

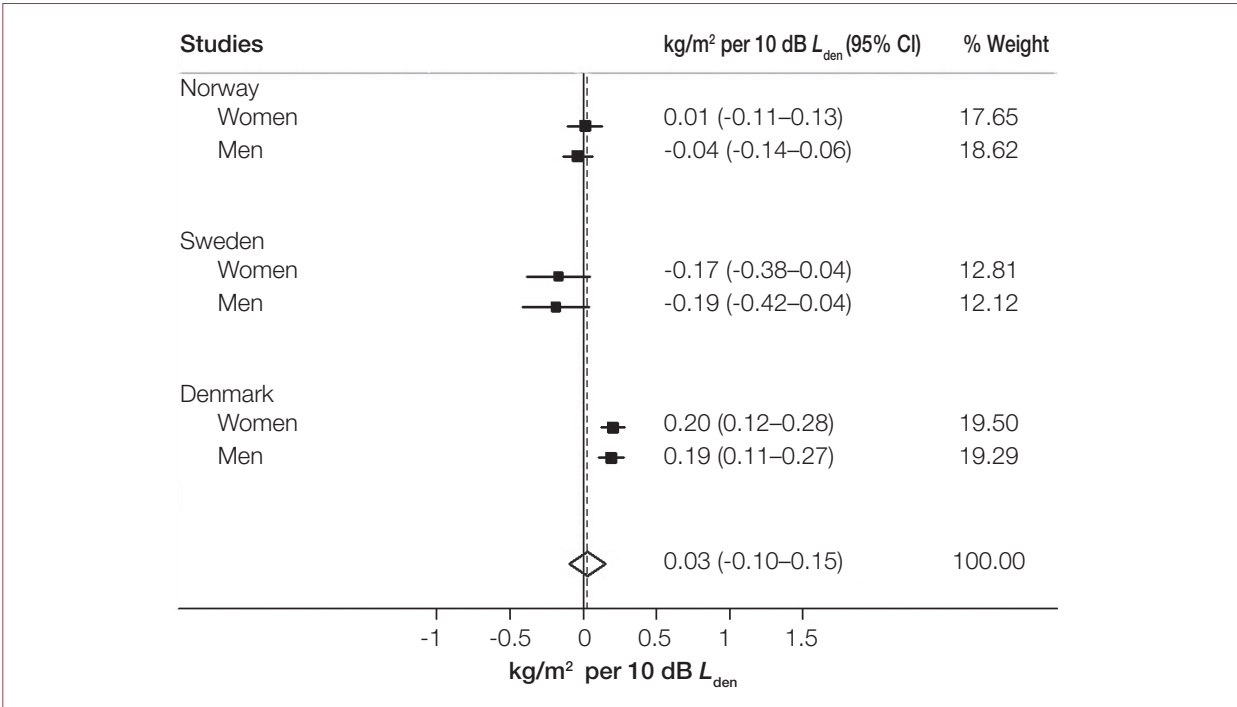
For the relationship between road traffic noise and the incidence of diabetes, one cohort study was identified, which included 57 053 participants and 2752 cases (Sørensen et al., 2013). The estimate of the effect was $RR = 1.08$ (95% CI: 1.02–1.14) per 10 dB L_{den} increase in noise across the range of 50–70 dB, and therefore the evidence was rated moderate quality.

Furthermore, two cross-sectional studies were identified that looked at the prevalence of diabetes (Selander et al., 2009; van Poll et al., 2014). The studies included 11 460 participants and 242 cases. Both studies reported a harmful effect of noise, and one showed a statistically significant association. However, the results were imprecise and with serious risk of bias, so the evidence was rated very low quality.

1.3.2 Obesity

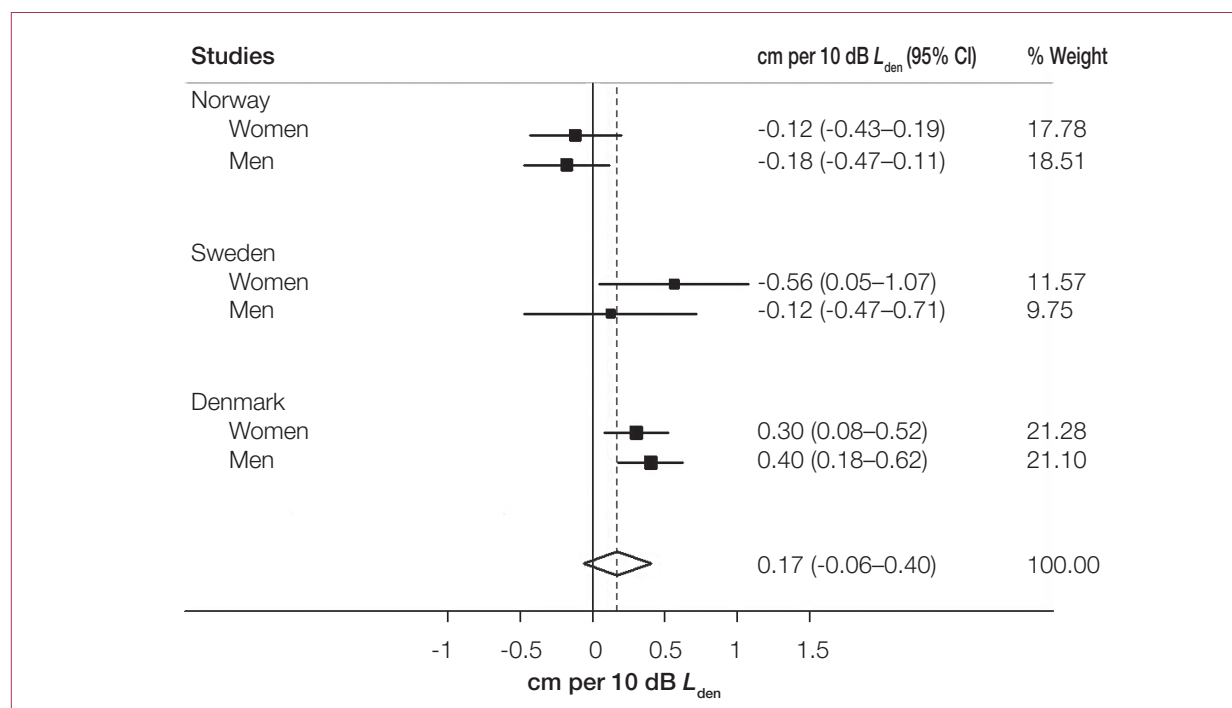
With regard to the association between road traffic noise and change in body mass index (BMI) and waist circumference, three cross-sectional studies were identified, with 71 431 participants (Christensen et al., 2016; Oftedal et al., 2014; 2015; Pyko et al., 2015). For each 10 dB increase in road traffic noise, there was a statistically nonsignificant increase in BMI of 0.03 kg/m² (95% CI: –0.10–0.15 kg/m²) and in waist circumference of 0.17 cm (95% CI: –0.06–0.40 cm). There was inconsistency in the results between the studies; therefore, for both associations, the evidence was rated very low quality (Fig. A4.1 and Fig. A4.2).

Fig. A4.1 The association between exposure to road traffic noise (L_{den}) and BMI in three Nordic studies



Notes: The black vertical line corresponds to no effect of noise exposure. The black dots correspond to the estimated slope coefficients per 10 dB for each sex in each study, with 95% CIs. The diamond designates summary estimates and 95% CIs based on random effects models. The dashed red line corresponds to these summary estimates. Heterogeneity between studies: $p = 0.000$; heterogeneity between genders: $p = 0.360$; overall (I-squared = 84.4%, $p = 0.000$). Weights are from random effect analysis.

Fig. A4.2 The association between exposure to road traffic noise (L_{den}) and waist circumference in three Nordic studies



Notes: The black vertical line corresponds to no effect of noise exposure. The black dots correspond to the estimated slope coefficients per 10 dB for each sex in each study, with 95% CIs. The diamond designates summary estimates and 95% CIs based on random effects models. The dashed red line corresponds to these summary estimates. Heterogeneity between studies: $p = 0.001$; heterogeneity between genders: $p = 0.842$; overall (I-squared = 69.0%, $p = 0.007$). Weights are from random effect analysis.

2. Railway noise

2.1 Adverse birth outcomes

No studies were found, and therefore no evidence was available on the association between railway noise and adverse birth outcomes.

2.2 Quality of life, well-being and mental health

Evidence rated very low quality was found for a weak effect of railway noise exposure on self-reported quality of life or health, albeit from a limited number of studies (Roswall et al., 2015; Torre et al., 2007). There was evidence rated moderate quality for an effect of railway noise on emotional and conduct disorders in childhood (Hjortebjerg et al., 2015), but no clear relationship between railway noise and children's hyperactivity (Hjortebjerg et al., 2015); this evidence was rated moderate quality.

2.3 Metabolic outcomes

2.3.1 Diabetes

One cohort study was identified that looked at the relationship between railway noise and the incidence of diabetes (Sørensen et al., 2013). The cohort study of 57 053 participants, including 2752 cases, found evidence rated moderate quality that there was no considerable effect of railway noise on diabetes, with an RR of 0.97 (95% CI: 0.89–1.05) per 10 dB L_{den} increase in noise.

Furthermore, one cross-sectional study was identified that looked at the relationship between railway noise and the prevalence of diabetes (van Poll et al., 2014), including 9365 participants and 89 cases. An RR of 0.21 (95% CI: 0.05–0.82) per 10 dB L_{den} increase in noise was found, but the reasons for the beneficial effect were not immediately apparent. The evidence in the study was rated very low quality.

2.3.2 Obesity

Regarding the association between railway noise and change in BMI and waist circumference, two cross-sectional studies were identified, with 57 531 participants (Christensen et al., 2016; Pyko et al., 2015). Christensen and colleagues observed a statistically significant increase of 0.18 kg/m² (95% CI: 0.00–0.36 kg/m²) per 10 dB for BMI and 0.62 cm (95% CI: 0.14–1.09 cm) per 10 dB for waist circumference in those exposed to railway noise, at levels above 60 dB L_{den} . Pyko and colleagues found a statistically significant increase in waist circumference of 0.92 cm (95% CI: 0.06–1.78 cm) per 10 dB L_{den} . The corresponding estimate for BMI was statistically nonsignificant, at 0.06 kg/m² (95% CI: –0.02–0.16 kg/m²). The evidence was rated low/very low quality.

3. Aircraft noise

3.1 Adverse birth outcomes

Evidence rated very low quality was available for an association between aircraft noise and pre-term delivery, low birth weight and congenital anomalies, as evidenced by six studies included in the systematic review (Ando & Hattori, 1973; Edmonds et al., 1979; Jones & Tauscher, 1978; Knipschild et al., 1981; Matsui et al., 2003; Schell, 1981). The potential for risk of bias in these was high and the results tended to be inconsistent.

3.2 Quality of life, well-being and mental health

Evidence rated very low quality was available for an effect of aircraft noise on medication intake for depression and anxiety (Floud et al., 2011). There was evidence rated very low quality for an effect of aircraft noise exposure on interview measures of depression and anxiety (Hardoy et al., 2005) and rated low quality for an association of aircraft noise with hyperactivity in children (Clark et al., 2013; Crombie et al., 2011; Stansfeld et al., 2009a).

The evidence showed, however, no substantial effect of aircraft noise on self-reported quality of life or health (Clark et al., 2012; Schreckenberget al., 2010a; 2010b; Stansfeld et al., 2005; van Kempen et al., 2010) or on emotional and conduct disorders in childhood (Clark et al., 2012; 2013; Crombie et al., 2011; Stansfeld et al., 2005; 2009a). This evidence was rated very low quality.

3.3 Metabolic outcomes

3.3.1 Diabetes

For the relationship between aircraft noise and incidence of diabetes one cohort study was identified, including 5156 participants and 1346 cases (Eriksson et al., 2014). The estimate of the effect was imprecise, with an RR of 0.99 (95% CI: 0.47–2.09) per 10 dB L_{den} increase in noise; the evidence was therefore rated very low quality.

Furthermore, one cross-sectional study was identified that looked at the prevalence of diabetes (van Poll et al., 2014), including 9365 participants and 89 cases. The RR was 1.01 (95% CI: 0.78–1.31) per 10 dB increase in aircraft noise. The evidence was rated very low quality.

3.3.2 Obesity

For the association between aircraft noise and change in BMI and waist circumference, one cohort study was identified, with 5156 participants (Eriksson et al., 2014). For each 10 dB increase in aircraft noise level, the increase in BMI was 0.14 kg/m² (95% CI: –0.18–0.45) (evidence rated low quality), and the increase in waist circumference was 3.46 cm (95% CI: 2.13–4.77) (evidence rated moderate quality). The range of noise levels in the study was 48–65 dB L_{den} . In the case of BMI, the change over the whole range in noise values was not statistically significant and was less than what could be considered clinically relevant (3–5% change in BMI); however, for waist circumference, the change was equivalent to an increase of 5.8 cm.

4. Wind turbine noise

4.1 Quality of life, well-being and mental health

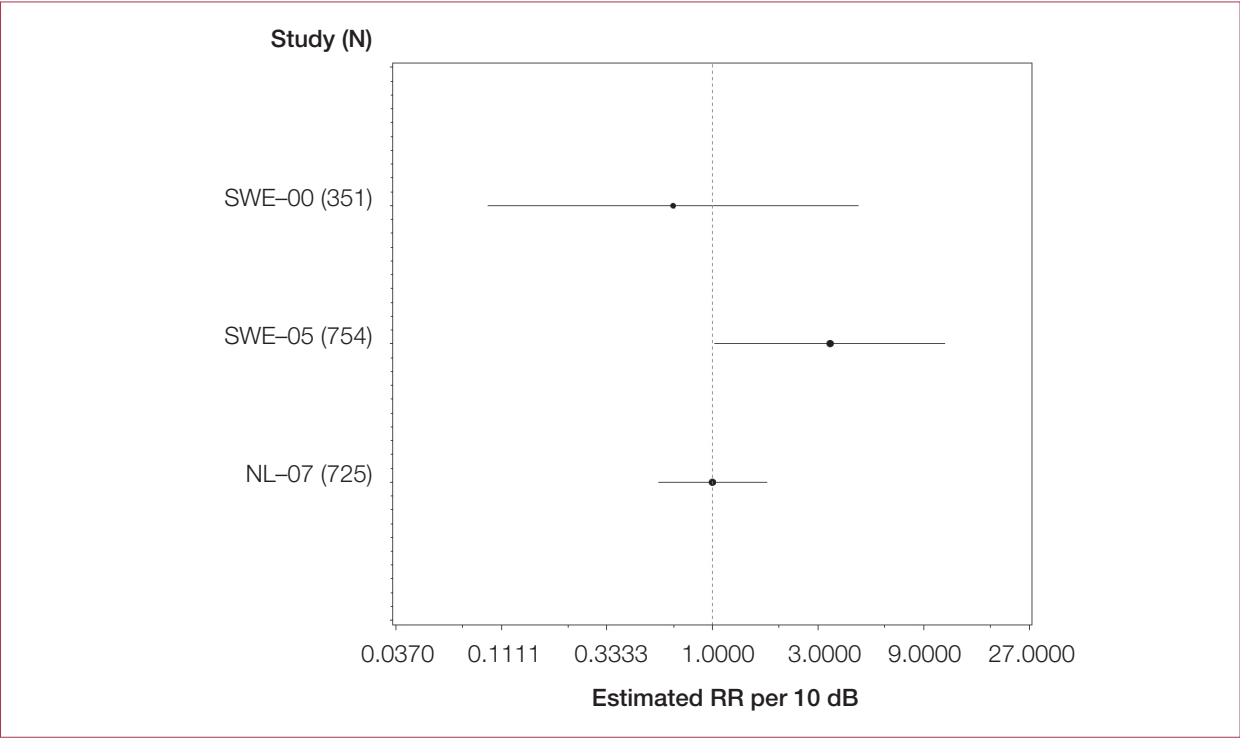
Five low-quality systematic reviews of wind turbine noise effects on mental health and well-being have been carried out (Ellenbogen et al., 2012; Kurpas et al., 2013; Merlin et al., 2013; Onakpoya et al., 2015; Schmidt & Klokke, 2014). These reviews differed in their conclusions and delivered inconsistent evidence that wind turbine noise exposure is associated with poorer quality of life, well-being and mental health. Therefore, the evidence for no substantial effect of wind turbine noise on quality of life, well-being or mental health was rated very low quality.

4.2 Metabolic outcomes

4.2.1 Diabetes

For the relationship between wind turbine noise and prevalence of diabetes, three cross-sectional studies were identified, with a total of 1830 participants (Bakker et al., 2012; Pedersen, 2011; Pedersen & Larsman, 2008; Pedersen & Persson Waye, 2004; 2007; Pedersen et al., 2009; van den Berg et al., 2008). The number of cases was not reported. The effect sizes varied across studies, and only one study found a positive association between exposure to wind turbine noise and the prevalence of diabetes; therefore, no meta-analysis was performed. Due to very serious risk of bias and imprecision in the results, this evidence was rated very low quality. As a result, there is no clear relationship between audible noise (greater than 20 Hz) from wind turbines or wind farms and prevalence of diabetes (Fig. A4.3).

Fig. A4.3 The association between exposure to wind turbine noise (sound pressure level) and self-reported diabetes



Note: The dotted vertical line corresponds to no effect of exposure to wind turbine noise. The black circles correspond to the estimated RR per 10 dB (sound pressure level) and 95% CI.
For further details on the studies included in the figure please refer to the systematic review on environmental noise and cardiovascular and metabolic effects (van Kempen et al., 2018).

5. Leisure noise

Owing to a lack of evidence meeting the criteria for systematic reviewing, no results for any of the important health outcomes can be given for exposure to leisure noise.

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The WHO Regional Office for Europe

The World Health Organization (WHO) is a specialized agency of the United Nations created in 1948 with the primary responsibility for international health matters and public health. The WHO Regional Office for Europe is one of six regional offices throughout the world, each with its own programme geared to the particular health conditions of the countries it serves.

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Noise is an important public health issue. It has negative impacts on human health and well-being and is a growing concern. The WHO Regional Office for Europe has developed these guidelines, based on the growing understanding of these health impacts of exposure to environmental noise. The main purpose of these guidelines is to provide recommendations for protecting human health from exposure to environmental noise originating from various sources: transportation (road traffic, railway and aircraft) noise, wind turbine noise and leisure noise. They provide robust public health advice underpinned by evidence, which is essential to drive policy action that will protect communities from the adverse effects of noise. The guidelines are published by the WHO Regional Office for Europe. In terms of their health implications, the recommended exposure levels can be considered applicable in other regions and suitable for a global audience.

ISBN 9789289053563



9 789289 053563 >

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