Team 5 Noise and sleep - a review of research from 2017-2021

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ABSTRACT

Sufficient sleep is important for cognitive functioning, as well as for good mental and physical health. To provide an overview of recent findings on the effects of noise on sleep, a literature review was conducted. Articles published since June 2017 were identified through a search in scientific databases. Studies on transportation, wind turbine, and hospital noise were included in this review. One major effort in this period was the comprehensive and systematic review to update the exposure-response associations for environmental noise and both self-reported and physiologically measured sleep, as the basis for the development of the WHO noise guidelines. Other, population-based studies have been published during this period, including studies on the effects on wind turbine noise on sleep medication use and effects of road traffic noise on children’s sleep. There has been an ongoing interest in acute physiologic effects of noise on sleep. Among the several field studies on aircraft noise is the first investigation on children. Research has continued into the mechanisms linking noise-induced sleep disruption with the development of disease, in both human and animal studies.

INTRODUCTION AND METHOD

It is well acknowledged that environmental noise at night-time impacts on sleep, both in terms of acute physiological effects as well as on self-reported sleep quality. The immediate effects of noise on sleep, may in turn influence on cognitive and day-time functioning. Moreover, it is biologically plausible that long-term exposure to night-time noise contribute to development of several adverse health effects such as diabetes, cardiovascular disease and cancer, as noise has been shown to affect endothelial function, stress hormone release and several cytokines involved in immunoregulation [1, 2].

According to a recent estimation from Europe, 6.5 million people suffer chronic high sleep disturbance due to environmental noise [3]. Road traffic is the major source of noise followed by railway and aircraft.

To provide an overview of recent findings on the effects of noise on sleep, a literature review was conducted. Articles published between April 2017 and April 2021 were identified through a search in scientific databases (SCOPUS, PubMed). Original research studies on transportation, wind turbine, and hospital noise were included in this narrative review.

RESULTS

Aircraft noise

Several new studies on aircraft noise and sleep have been reported during this ICBEN period (2017-2021). A pair of pilot studies on the effects of nocturnal aircraft noise on physiologic awakenings and self-reported outcomes were performed around airports in the USA [4-6]. These studies found exposure-response functions between the maximum indoor sound pressure level (SPL) of discrete aircraft noise events and increased probability of physiologic awakenings, derived from body movements and increases in heart rate. Furthermore, there were indications that higher levels of calculated L_{night} outdoors was associated with decreased sleep quality and increased prevalence of sleep disturbance.

Exposure to maximum SPL from aircraft overflights was also found to impact on heart rate during sleep in a field study of residents near airports in France [7]. Moreover, this study supported previous findings of no habituation to noise during sleep, as participants living more than five years at their current dwelling responded similarly to those of the whole study population. Furthermore, an association between aircraft noise (L_{den}, L_{night}) and self-reported total sleep duration was found in the DEBATS study population of about 1,200 individuals (around three international airports in France [8]. The same investigators also examined the impact on sleep quantity and quality assessed via wrist actigraphy in n=112 subjects [9]. Higher average indoor noise levels from aircraft traffic were associated with increased odds of taking more than 30 minutes to fall asleep, spending more than 9 hours in bed, and sleeping for less than 6 hours. Higher levels of noise indicators of discrete aircraft events were not only associated with increased time in bed and lower sleep time, but also with increased wakefulness after sleep onset (WASO) and reduced sleep efficiency. These findings lend some support to the idea that event-level indicators of noise may be more relevant for noise-induced sleep disruption by aircraft than energetically averaged levels over the night.

A cross-sectional study from Poland found a positive association between nocturnal aircraft noise and risk of insomnia measured by the Athens Insomnia Scale (AIS) [10]. Blood pressure was also measured in this study and a significant interaction between aircraft noise exposure and the AIS score was demonstrated.

Schmidt et al. [11] conducted a blinded study of night-time aircraft noise exposure in volunteers with cardiovascular disease (CVD) or at increased cardiovascular risk. In total 70 participants were exposed in a randomised sequence to one control night (L_{Aeq} = 37 dB) and two noisy nights in their own homes. Recorded aircraft noise events with different peak sound pressure levels in two different scenarios were played back, either 60 or 120 noise events, but resulting in an equal average sound pressure level (L_{Aeq} = 45 dB). Measurements of cardiac and vascular function were undertaken in addition to measurements of sleep (questionnaire and polysomnographic [PSG] recordings). Both night-time noise exposure scenarios resulted in a deterioration of subjective sleep quality, vascular function, and impairment in cardiac diastolic function. However, no differences in sleep were found measured with PSG either between the two noise scenarios or between the noise scenarios and the control situation [11].

A large study from Switzerland used a time-stratified case-crossover study design to explore acute effects of aircraft noise events on cardiovascular mortality in individuals from the Swiss

National Cohort living near Zürich Airport [12]. Modelled levels of aircraft noise events with high spatial and temporal accuracy were analysed with regard to mortality data, including hour and cause of death. For night-time deaths, exposure levels 2 h preceding death were statistically significantly associated with mortality for all causes of CVD (OR = 1.44, 95%CI: 1.03 - 2.04 for the highest exposure group L_{Aeq} > 50 dB vs. 20 dB). Most consistent associations were observed for ischaemic heart diseases, myocardial infarction, heart failure, and arrhythmia [12].

A recent study in mice found that aircraft noise during sleep, but not wake, caused increased blood pressure, endothelial dysfunction, oxidative stress and inflammation [13]. Studies such as these provide insight into the pathophysiology that may underlie epidemiological observations linking chronic aircraft noise exposure, and indeed potentially other traffic modes, with CVD.

Road traffic noise

Most studies on road traffic noise and sleep during this period were population-based or field studies. Three Nordic studies examined the association between modelled night-time road traffic noise and sleep medication use. One of these, a survey among residents of the Helsinki Capital Region of Finland (N=7,000), revealed no association between night-time outdoor road traffic noise and self-reported sleep medication use [14]. This is in accordance with previous findings on nocturnal road traffic noise and self-reported use of sleep medications [15, 16]**.** A Norwegian study used data from the Health and Environment in Oslo study (HELMILO), a population-based survey of about 13,000 adults whose data were linked to the prescription registry. This study found some evidence for an association with prescribed sleep medication, but only during the summer season [17]. Lastly, results from a nationwide danish study suggest that long-term residential exposure to night-time road traffic noise at the most exposed façade may increase the risk of redeeming sleep medication, primarily among men [18]. The association seemed strongest among already high-risk subpopulations of smokers and physically inactive.

A cross-sectional study of the Respiratory Health in Northern Europe (RHINE) III population (n=12,963) found statistically significant associations between self-reported traffic noise and all three insomnia symptoms: difficulty initiating sleep (the odds ration (OR) = 3.54; 95% confidence interval (CI): 1.85, 6.76), difficulty maintaining sleep (OR = 2.95; 95% CI: 1.62, 5.37), and early morning awakening (OR = 3.25; 95% CI: 1.97, 5.37) [19].

Although considered a vulnerable group [20] less research has been done on children. One of the few studies on noise and children's sleep found that increased nocturnal road traffic noise was associated with reduced sleep duration for girls, but not in boys [21]. This study was based on parental report of children's sleep, and used data from children at the age of 7 from the Norwegian Mother, Father and Child cohort study (MoBa). A follow up on this study indicated that road traffic noise has a negative impact on children's inattention, but found limited evidence for a mediation by sleep duration [22]. Another cross-sectional study of children 8-12 from Poland found that parental reports of children`s sleep quality and inattention were both associated with surrogate indices of exposure to traffic-related noise [23]. In multivariate models sleep disturbances and attention disorders were more likely to occur in children living in the area with higher traffic density (OR = 1.44; 95% CI: 1.05-1.97 and 1.38; 95% CI: 1.03-1.86, respectively) [23].

One large field study by Röösli et al. [24] measured sleep with actigraphy and included in total 105 individuals recruited from a previous survey. In total 624 nights with night-time noise and sleep measurements were analysed. The study suggests that noise exposure in the early morning hours is probably most crucial for a negative impact on objective sleep efficiency and self-reported sleep quality. However, evening noise exposure was also associated with longer sleep latency.

One laboratory study on low levels (37 dB $L_{AEq,8h}$) of road traffic noise found that there was a lower amount of N3 (deep) sleep in nights with road noise relative to a quiet control night (around 10 minutes/1-2% of total sleep time less), whereas other measures of sleep structure or sleep fragmentation were not significantly impacted [25].This study also investigated whether there were differential effects of noise spectrum and sleep, and found that retrospective self-reported sleep disturbance was higher in nights with high frequency noise than low frequency noise, although there were no differences between conditions for physiologic sleep.

Railway noise

New studies on railway noise typically focused on acute effects on physiologic sleep parameters, with some studies considering noise in combination with railway vibration. A laboratory study found that low levels of ground-borne noise from railway tunnels (L_{night} 18.5-22.1 dB; $L_{AF,max}$ 40-45 dB) induced cortical and cardiac arousal [26]. Notably this effect was due to train noise of a spectral profile with reduced low-frequency (31.5-100 Hz) and increased higher-frequency (125-800 Hz) components, whereas railway events with the same A-weighted level but greater power at low-frequencies had a reduced or even no effect. Herzog et al. [27] performed a field study exposing subjects to noise at home, and found that 60 nocturnal railway noise events were associated with endothelial dysfunction and substantial changes in the blood plasma proteome, offering mechanistic insights into increased cardiovascular risk following chronic noise exposure. Persson Waye et al. [28] reported exposure-response relationships for railway vibration and self-reported sleep disturbance from field studies in The Netherlands (n=130) and Poland (n=104) and laboratory studies in Sweden (n=59). Vibration exposure was associated with sleep disturbance (OR=3.51 per log10 Root Mean Square increase in night-time vibration). Vibration was also investigated in the laboratory by Smith et al. [29], who found that not only did both noise and vibration induce cardiovascular and cortical arousal, and changes of sleep structure and depth, but also that the effects of noise and vibration were additive for cortical arousals and changes of sleep stage.

Multiple transportation sources

In their comprehensive review commission by WHO, Basner and McGuire, presented updated exposure-response estimates for the association between noise from road, rail and aircraft and both self-reported and physiologically measured sleep [30]. Meta-analyses of the results from studies using self-reported sleep, with or without referring to noise in the question, were performed separately. The odds ratio (OR) for the percent highly sleep disturbed (%HSD) per 10 dB increase in L_{night} was statistically significant for all three transportation modes when the sleep disturbance question referred to noise. The OR was highest for railway noise followed by road and aircraft noise. The meta-analysis including only studies with general sleep questions, without referring to noise, found no statistically significant association with L_{night}.

The pooled analysis of results from polysomnographic studies on acute effects of transportation noise on sleep revealed statistically significant associations between indoor L_{max} for single events and the probability of awakening [30]. In contrast to the difference in exposure-response for road, rail and aircraft noise when measured by self-reports and referred to noise, no difference between the transportation modes were observed on the acute effects on physiologically measured sleep. None of the presented estimates were adjusted for potential confounding.

Elmenhorst et al. [31] conducted an analysis of data pooled from three German laboratory studies to elucidate differential impacts of noise from road, rail and air traffic on physiological awakening probability to discrete noise events. For traffic events with the same noise level, the awakening probability increased in the order aircraft < road < railway noise, even after adjusting for acoustical factors. This is in contrast to the findings from the WHO review in which the OR for the association between noise indices for single noise events and awakening probability was source independent [30].

The Swiss SiRENE study explored associations between night-time noise from road, rail and aircraft and self-reported sleep using the ICBEN style 5-point response scale [32]. Exposure-response associations were presented, including adjustments for potential confounding factors. In this study, Brink et al. [32] also examined the effect of several potential effect modifiers, and found that bedroom orientation had a strong effect, equal to a nearly 20 dB reduction in noise level at the most exposed façade. Other factors such as window position (open, tilted, closed), survey season or temperature had no effect on the association between L_{night} and %HSD in this study [32]. In contrast, a previous large population based study from Norway demonstrated stronger associations between L_{night} from road traffic and sleep medications during the summer season [17], suggesting that window opening habits may have some effect.

The SiRENE study also explored different traffic noise sources and relationships with a number of physiologic aspects of sleep in the laboratory. Contrary to some earlier studies, it was found that sleep spindle density did not offer a protective role in preserving sleep in the face of noise [33]. Electroencephalogram (EEG) arousal rates were higher during nights with eventful road or rail noise compared to a quiet control night, but the same association was not seen for nights with continuous road noise that had the same average hourly noise level [34].

Several nights of traffic noise exposure also impaired glucose tolerance and insulin sensitivity [35], and there were some indications that more eventful noise could be particularly deleterious, which may be a pathway through which chronic noise exposure leads to diabetes.

Finally, the laboratory studies found no effect of transportation noise on sleep macrostructure, inflammation, blood pressure, mean heart rate, nocturnal catecholamine levels or morning cytokine levels [36], but did observe an increase in the evening cortisol levels and cumulative duration of autonomic arousals for intermittent noise nights. Taken together, these findings suggest that nocturnal noise can have adverse biological consequences without necessarily disrupting classically-scored sleep micro- and macrostructure.

Two animal studies shed light on the possible metabolic effects of night-time noise. One of these studies found that environmental noise exposure disturbed sleep, affected energy metabolism and feeding, leading to increased weight gain in female rats [37]. Another, similar study also demonstrated that sub-chronic high-level noise exposure was associated with sleep perturbations, hyperphagia, and weight gain in juvenile rats [38]. The last study also observed greater mean thymus weight in the noise exposed group of rats, which might indicate an effect of stress. Thus, the observed effects on weight gain could have been due to a combination of effects on sleep and stress pathways.

At least two recent studies have considered environmental noise and effects on sleep in a wider context of the built environment. In the large Multi-Ethnic Study of Atherosclerosis

(MESA), in which sleep was assessed in a subsample of *n*=1,889 subjects via wrist actigraphy, neighbourhood-level survey-based noise exposure was associated with higher odds of short sleep duration (OR=1.2; 95%CI: 1.0 -1.4) and decreased average sleep efficiency (adjusted mean difference -0.2%; 95% CI: −0.4 −0.1)) [39]. Interestingly, more walkable environments were associated with poorer sleep outcomes, which may be a result of increased urbanisation and the environmental stressors present in such settings. However, this association was attenuated when noise was taken into consideration, indicating that noise is at least partly responsible. Mayne et al. [40] also used actigraphy to study associations between sleep and the built environment, but among adolescents. Increased noise levels in summer (data from other seasons were not examined) were associated with later sleep timing and an increased odds of sleeping <8 hours. Increased tree canopy cover was associated with earlier sleep timing, which could be a result of various sleep-promoting or sleep-protecting factors of greenery, including perhaps lower noise levels or attenuation of noise from nearby traffic sources.

One consequence of insufficient sleep is daytime sleepiness, which is further linked to increased risk of occupational and vehicle accidents [41], lower professional performance and poorer health [42]. A population-based cross sectional study from Lausanne in Switzerland obtained measures of daytime sleepiness using the Epworth Sleepiness Scale, from an adult cohort of nearly 3,700 individuals [43]. Outdoor residential night-time noise levels from road and rail were modelled for each respondent. Spatial analysis of sleepiness revealed high degree of spatial clustering, and further that the median night-time traffic noise was statistically significantly different across the three (low, medium, high) sleepiness clusters, also when adjusted for potential confounding factors such as body mass index (BMI) and area level income [43]. Night-time noise and sleepiness were weakly correlated without accounting for the spatial component.

A large nationwide danish study found an association between noise from road and rail and increased risk of breast cancer [44]. One hypothesised mechanism for this association is that night-time noise may negatively affect the circadian rhythm. Disruption of the circadian rhythm through night shift work is classified as “probably carcinogenic to humans” and could thus represent a potential pathway between noise and breast cancer. The association was stronger when using L_{night} at the least exposed façade. Since the bedroom is often at the more shielded side of the house, the results give some supports to the notion that impact on sleep mediates the association.

Wind turbine noise

There is continued interest in the effect of wind turbine noise (WTN) on sleep, even though the noise levels are low relative to other environmental noise sources, and few persons are affected by noise from wind turbines compared to transportation noise.

A series of Swedish laboratory studies found that self-reported sleep was consistently worse after a night with continuous WTN, and that there was a reduced amount of Rapid Eye Movement (REM) sleep compared to a quiet control night (-11.1 minutes) [45, 46]. The effects on REM were seen both in subjects chronically exposed to WTN at home and WTN-naïve controls, suggesting a lack of habituation or sensitisation. There were no effects of WTN on a number of key physiologic indicators of disturbance including sleep latency, sleep efficiency, awakenings, or biomarkers of stress response. The lack of effects of WTN on sleep duration and awakenings were supported by a Canadian actigraphy field study [47] which did however find some indications that high variability in WTN levels across the night may have a modest effect on awakenings.

In a cross-sectional survey around three independent wind farms in Finland, a positive association between the modelled outdoor sound pressure levels from wind turbines and self-reported sleep was observed [48]. Women and those reporting to be noise sensitive were more likely to report sleep problems due to WTN.

A nationwide danish study found that five-year mean outdoor night-time WTN of ≥42 dB was associated with a hazard ratio (HR) = 1.14 [95% confidence interval (CI]: 0.98, 1.33) for redemption of sleep medication [49]. The association was strongest among the persons > 65 years of age. However, no consistent findings were observed for indoor WTN, even though indoor noise most likely better reflects exposure during sleep.

It remains unclear how to reconcile self-reported sleep disturbance by WTN with the lack of, or only modest, effects on sleep physiology and motility. One intriguing possibility is that classical analysis and sleep-scoring methodologies do not adequately capture subtle yet clinically-relevant effects on sleep. For example, Lechat et al. found that K-complexes, which are prominent bi- or tri-phasic waveforms in the EEG during established sleep, were more sensitive markers of sleep disturbance by WTN and road traffic noise than EEG arousals and awakenings [50]. Future studies may reveal much in this regard, not only for WTN but also for other sources of environmental noise.

Hospital noise

Because of the importance of adequate quality and quantity of sleep in recovery, there has been continued interest in how sleep of patients is disrupted by noise in clinical settings. One study found that noise was the most common environmental factor affecting sleep among ICU patients, affecting 32.4% of 71 patients surveyed [51]. In this study, noise negatively impacted the sleep of younger (≤55 years) patients in particular. The sleep of pediatric patients, who are a particularly vulnerable group due to the importance of sleep for development, has been little researched over the last 4 years however, although higher noise levels and reduced sleep quantity and quality were reported in hospitals than at home, for children [52, 53].

Sleep and noise in intensive care units (ICUs) has also received continued interest. Younis et al. found a negative small but significant correlation (r= -0.42; p<.001) between nighttime noise levels in an ICU and self-reported sleep quality, as determined via the Richards-Campbell Sleep Questionnaire (RCSQ) [54]. Similar findings of increased noise levels being associated with lower RCSQ scores, in a study of 64 patients across six ICUs, were reported by Simons et al. [55]. There is also some evidence that not only perceived sleep quality, but also objective sleep structure is adversely affected by noise in clinical settings. Associations between ICU noise and impaired sleep were also found by Elbaz et al., who reported exposure-response relationships for increased risk of awakening from physiologically-measured sleep as sound pressure levels increased, during both day- and night-time [56].

There is increasing awareness of the importance of a quiet noise environment at night, and a number of quantitative and qualitative interventions have been successful in lowering hospital noise levels [57-59]. One of these studies also investigated subjective patient outcomes, and found increased satisfaction with noise levels and ability to rest following an educational intervention designed to reduce staff contributions to noise [59]. Other investigators have deployed interventions designed to reduce the noise exposure of patients by use of earplugs, usually in combination with eye masks. When providing these interventions to craniotomy patients, Arik et al. [60] found higher RCSQ sleep quality and increased melatonin secretion compared to patients who received standard care. Koçak and Arslan also found improved sleep quality, assessed via the RCSQ, when providing ICU patients with earplugs and eye masks [61]. Demoule et al. [62] found that ICU patients wearing earplugs and eye masks had on average 10 fewer prolonged (>1 minute) awakenings, assessed via PSG, than patients not receiving the interventions. They did not see overall differences between the two study groups for total sleep time or sleep macrostructure, but in a subgroup analysis did observe that patients who wore the earplugs all night long had a higher proportion of N3 (deep) sleep than the control group.

SUMMARY

Studies on transportation, wind turbine, and hospital noise were included in this review of research on noise and sleep since the last ICBEN conference in 2017. One major effort in this period was the development of the WHO noise guidelines including updated noise recommendations for night-time noise for specific sources to protect the public. These were based on the comprehensive and systematic review to update the exposure-response associations for transportation noise and WTN and both self-reported and physiologically measured sleep [30]. Since then, studies on aircraft noise are reported from various countries, including Italy [63], France [8], and Vietnam [64]. Several transportation modes are included in studies conducted in Switzerland [32] and in China [65]. Knowledge on the effects of noise on children's sleep is still sparse, but during this period, at least a couple of studies have been conducted on the association between road traffic noise and children's sleeping problems [21, 23].

We see a tendency towards the use of more standardized general sleep disturbance questions e.g. insomnia symptoms and other questions that do not ask specifically about noise as the source of sleep disturbances. Some population based studies have also explored the association between night-time noise and register based sleep medication use, where two Nordic studies examined the association with road traffic noise [17, 18] and another study from Denmark examined the association with wind turbine noise [49]. Furthermore, the role of contextual factors (effect modifiers) such as bedroom orientation, access to quite side etc. is also addressed in some studies e.g. [32]. Common for these studies is the reporting of risk estimates adjusted for potential confounders.

Research on WTN on sleep is still revealing none, or only modest effects on sleep physiology. It may be that subtle, yet clinically relevant, effects on sleep are difficult to capture with classical analysis and sleep-scoring methodologies. There is increasing awareness of the importance of a quiet noise environment at night, and a number of quantitative and qualitative interventions have been successful in lowering hospital noise levels [57-59].

Furthermore, there has been an ongoing interest in acute physiologic effects of noise on sleep. Research has also continued into the mechanisms linking noise-induced sleep disruption with the development of disease, in both human and animal studies. Recent findings suggest that nocturnal noise can have adverse biological consequences without necessarily disrupting the micro- and macrostructure of sleep e.g. [66, 67]. Several studies during this period have shed new light on the role of sleep in the noise health relationship e.g. [7, 27, 36, 67].

While the majority of studies using physiologic sleep measurements have been conducted in the laboratory, there have been an increasing number of physiologic investigations in field settings. This trend seems likely to continue. However, there is still a paucity of studies using more innovative strategies for obtaining data e.g. using new smart phone device apps or wearable technologies to measure sleep in larger populations.

FUTURE PERSPECTIVES

One issue encountered in the WHO meta-analysis was the disparity in sleep questions and response scales used in different studies [30]. Standardisation and validation of questions on the effects of noise on sleep, as with the ICBEN annoyance question [68], could aid similar future efforts as well as improving inter-study comparability. Furthermore, the use of more standardized general sleep disturbance questions e.g. insomnia symptoms and other questions that do not ask specifically about noise as the source of sleep disturbances, should also be encouraged, as this is important to avoid bias and for comparability with other risk factors for sleep disturbances.

There were several field studies conducted in the past four years, however many of those used self-reported or movement-derived (actigraphy) measures of sleep. These are important outcomes but do not provide information regarding physiologic sleep structure. Recent advances in wearable sleep-recording technologies open up the possibility of measuring sleep in the field at a scale that has not previously been possible [69, 70]. Such studies would continue to shed light on the pathophysiological mechanisms linking chronic noise exposure with the development of disease. Further, ongoing research on the development of biomarkers for chronic sleep deprivation [71, 72] is worth following, to develop innovative studies that can provide new knowledge of long-term exposure to night-time noise on health.

The nature of environmental noise exposure is changing. For example, there is an increasing prevalence of electric automobiles as well as personal and commercial drones. Supersonic passenger aircraft are currently under development and may enter the market in the next few years. These emerging noise sources will change the acoustical characteristics of environmental noise, including sonic booms. Future research should aim to understand the impact this will have on the sleep of exposed populations.

The interaction of different exposures, such as noise and air pollution, on health has been of interest in the field for some time. Recently, the concept of the human exposome – which comprises of the complete overall exposure to external, internal and social/personal factors throughout life from conception onwards – has been gaining interest. Two major ongoing European research projects, Equal-Life (https://www.equal-life.eu/en) and Advancing Tools for Human Early Lifecourse Exposome Research and Translation (ATHLETE; https://athleteproject.eu/), aim to further the understanding of how noise, sleep, and other exposome factors (e.g. urban built environment), interact and contribute to children's and adolescent's development and physical and mental health. Emerging –omics domains as well as advances in data science, integration and modelling ("big data") will connect high-dimensional "big data" to biomedical and public health/epidemiological knowledge [73].

REFERENCES

1. Daiber, A., et al., *Environmental noise induces the release of stress hormones and inflammatory signaling molecules leading to oxidative stress and vascular dysfunction—Signatures of the internal exposome.* BioFactors, 2019. **45**(4): p. 495-506.
2. Münzel, T., et al., *Adverse cardiovascular effects of traffic noise with a focus on nighttime noise and the new WHO noise guidelines*, in *Annual Review of Public Health*. 2019. p. 309-328.
3. European Environment Agency., *Environmental noise in Europe - 2020. EEA Report No 22/2019*. 2019.
4. Basner, M., M. Witte, and S. McGuire, *Aircraft Noise Effects on Sleep-Results of a Pilot Study Near Philadelphia International Airport.* Int J Environ Res Public Health, 2019. **16**(17).
5. Rocha, S., et al., *Survey Results of a Pilot Sleep Study Near Atlanta International Airport.* Int J Environ Res Public Health, 2019. **16**(22).

6. Smith, M.G., et al., *On the feasibility of measuring physiologic and self-reported sleep disturbance by aircraft noise on a national scale: A pilot study around Atlanta airport.* Science of the Total Environment, 2020. **718**.
7. Nassur, A.M., et al., *Effects of aircraft noise exposure on heart rate during sleep in the population living near airports.* International Journal of Environmental Research and Public Health, 2019. **16**(2).
8. Nassur, A.M., et al., *Aircraft Noise Exposure and Subjective Sleep Quality: The Results of the DEBATS Study in France.* Behavioral Sleep Medicine, 2019. **17**(4): p. 502-513.
9. Nassur, A.M., et al., *The impact of aircraft noise exposure on objective parameters of sleep quality: results of the DEBATS study in France.* Sleep Medicine, 2019. **54**: p. 70-77.
10. Rojek, M., et al., *The relation of nocturnal exposure to aircraft noise and aircraft noise-induced insomnia with blood pressure.* Pol Arch Intern Med, 2021. **131**(1): p. 33-41.
11. Schmidt, F.P., et al., *The impact of aircraft noise on vascular and cardiac function in relation to noise event number: a randomized trial.* Cardiovasc Res, 2021. **117**(5): p. 1382-1390.
12. Saucy, A., et al., *Does night-time aircraft noise trigger mortality? A case-crossover study on 24 886 cardiovascular deaths.* Eur Heart J, 2021. **42**(8): p. 835-843.
13. Kröller-Schön, S., et al., *Crucial role for Nox2 and sleep deprivation in aircraft noise-induced vascular and cerebral oxidative stress, inflammation, and gene regulation.* Eur Heart J, 2018. **39**(38): p. 3528-3539.
14. Okokon, E.O., et al., *Traffic noise, noise annoyance and psychotropic medication use.* Environment International, 2018. **119**: p. 287-294.
15. de Kluizenaar, Y., et al., *Long-term road traffic noise exposure is associated with an increase in morning tiredness.* The Journal of the Acoustical Society of America, 2009. **126**(2): p. 626-633.
16. Evandt, J., et al., *A population-based study on nighttime road traffic noise and insomnia.* Sleep, 2017. **40**(2).
17. Evandt, J., et al., *Road traffic noise and registry based use of sleep medication.* Environmental Health: A Global Access Science Source, 2017. **16**(1).
18. Roswall, N., et al., *Nighttime road traffic noise exposure at the least and most exposed façades and sleep medication prescription redemption—A Danish cohort study.* Sleep, 2020. **43**(8).
19. Janson, E., et al., *Insomnia associated with traffic noise and proximity to traffic-a cross-sectional study of the Respiratory Health in Northern Europe III population.* J Clin Sleep Med, 2020. **16**(4): p. 545-552.
20. WHO, *Night noise guidelines for Europe*. 2009: WHO Regional Office for Europe.
21. Weyde, K.V., et al., *Nocturnal Road Traffic Noise Exposure and Children's Sleep Duration and Sleep Problems.* Int J Environ Res Public Health, 2017. **14**(5).
22. Weyde, K.V., et al., *Road traffic noise and children's inattention.* Environmental Health: A Global Access Science Source, 2017. **16**(1).
23. Skrzypek, M., et al., *Impact of road traffic noise on sleep disturbances and attention disorders amongst school children living in upper Silesian Industrial Zone, Poland.* International Journal of Occupational Medicine and Environmental Health, 2017. **30**(3): p. 511-520.
24. Röösli, M., et al., *Associations of various nighttime noise exposure indicators with objective sleep efficiency and self-reported sleep quality: A field study.* International Journal of Environmental Research and Public Health, 2019. **16**(20).
25. Myllyntausta, S., et al., *Effect of the frequency spectrum of road traffic noise on sleep: A polysomnographic study.* J Acoust Soc Am, 2020. **147**(4): p. 2139.
26. Smith, M.G., et al., *Effects of ground-borne noise from railway tunnels on sleep: A polysomnographic study.* Building and Environment, 2019. **149**: p. 288-296.
27. Herzog, J., et al., *Acute exposure to nocturnal train noise induces endothelial dysfunction and pro-thromboinflammatory changes of the plasma proteome in healthy subjects.* Basic Res Cardiol, 2019. **114**(6): p. 46.
28. Persson Waye, K., et al., *Assessing the exposure-response relationship of sleep disturbance and vibration in field and laboratory settings.* Environmental Pollution, 2019. **245**: p. 558-567.
29. Smith, M.G., et al., *Physiological effects of railway vibration and noise on sleep.* J Acoust Soc Am, 2017. **141**(5): p. 3262.

30. Basner, M. and S. McGuire, *WHO Environmental Noise Guidelines for the European Region: A Systematic Review on Environmental Noise and Effects on Sleep.* International Journal of Environmental Research and Public Health, 2018. **15**(3): p. 519.
31. Elmenhorst, E.M., et al., *Comparing the effects of road, railway, and aircraft noise on sleep: Exposure–response relationships from pooled data of three laboratory studies.* International Journal of Environmental Research and Public Health, 2019. **16**(6).
32. Brink, M., et al., *Self-reported sleep disturbance from road, rail and aircraft noise: Exposure-response relationships and effect modifiers in the SiRENE study.* International Journal of Environmental Research and Public Health, 2019. **16**(21).
33. Rudzik, F., et al., *Sleep spindle characteristics and arousability from nighttime transportation noise exposure in healthy young and older individuals.* Sleep, 2018. **41**(7).
34. Rudzik, F., et al., *Ultradian modulation of cortical arousals during sleep: effects of age and exposure to nighttime transportation noise.* Sleep, 2020. **43**(7).
35. Thiesse, L., et al., *Adverse impact of nocturnal transportation noise on glucose regulation in healthy young adults: Effect of different noise scenarios.* Environment International, 2018. **121**: p. 1011-1023.
36. Thiesse, L., et al., *Transportation noise impairs cardiovascular function without altering sleep: The importance of autonomic arousals.* Environmental Research, 2020. **182**.
37. Coborn, J.E., et al., *Noise-induced sleep disruption increases weight gain and decreases energy metabolism in female rats.* International Journal of Obesity, 2019. **43**(9): p. 1759-1768.
38. De Jenlis, A.B., et al., *Impacts of subchronic, high-level noise exposure on sleep and metabolic parameters: A Juvenile rodent model.* Environmental Health Perspectives, 2019. **127**(5).
39. Johnson, D.A., et al., *Associations between the Built Environment and Objective Measures of Sleep.* American Journal of Epidemiology, 2018. **187**(5): p. 941-950.
40. Mayne, S.L., et al., *Associations of the residential built environment with adolescent sleep outcomes.* Sleep, 2021.
41. Horne, J.A. and L.A. Reyner, *Sleep related vehicle accidents.* Bmj, 1995. **310**(6979): p. 565-7.
42. Pagel, J.F., *Excessive daytime sleepiness.* Am Fam Physician, 2009. **79**(5): p. 391-6.
43. Joost, S., et al., *Spatial clusters of daytime sleepiness and association with nighttime noise levels in a Swiss general population (GeoHypnoLaus).* International Journal of Hygiene and Environmental Health, 2018. **221**(6): p. 951-957.
44. Sørensen, M., et al., *Road and railway noise and risk for breast cancer: A nationwide study covering Denmark.* Environmental Research, 2021. **195**.
45. Ageborg Morsing, J., et al., *Wind Turbine Noise and Sleep: Pilot Studies on the Influence of Noise Characteristics.* Int J Environ Res Public Health, 2018. **15**(11).
46. Smith, M.G., et al., *A laboratory study on the effects of wind turbine noise on sleep: Results of the polysomnographic WiTNES study.* Sleep, 2020. **43**(9): p. 1-14.
47. Michaud, D.S., et al., *Sleep actigraphy time-synchronized with wind turbine output.* Sleep, 2021.
48. Radun, J., V. Hongisto, and M. Suokas, *Variables associated with wind turbine noise annoyance and sleep disturbance.* Building and Environment, 2019. **150**: p. 339-348.
49. Poulsen, A.H., et al., *Impact of Long-Term Exposure to Wind Turbine Noise on Redemption of Sleep Medication and Antidepressants: A Nationwide Cohort Study.* Environmental health perspectives, 2019. **127**(3): p. 37005.
50. Lechat, B., et al., *K-complexes are a sensitive marker of noise-related sensory processing during sleep: A pilot study.* Sleep, 2021.
51. Miranda-Ackerman, R.C., et al., *Associations between stressors and difficulty sleeping in critically ill patients admitted to the intensive care unit: A cohort study.* BMC Health Services Research, 2020. **20**(1).
52. Bevan, R., et al., *Sleep quality and noise: Comparisons between hospital and home settings.* Archives of Disease in Childhood, 2019. **104**(2): p. 147-151.
53. Crawford, S., et al., *Quality of Sleep in a Pediatric Hospital: A Descriptive Study Based on an Assessment of Interruptions, Perceptions, and the Environment.* Journal of Nursing Administration, 2019. **49**(5): p. 273-279.
54. Bani Younis, M., F. Hayajneh, and J.A. Alshraideh, *Effect of noise and light levels on sleep of intensive care unit patients.* Nursing in Critical Care, 2021. **26**(2): p. 73-78.

55. Simons, K.S., et al., *Noise in the intensive care unit and its influence on sleep quality: A multicenter observational study in Dutch intensive care units.* Critical Care, 2018. **22**(1).
56. Elbaz, M., et al., *Sound level intensity severely disrupts sleep in ventilated ICU patients throughout a 24-h period: a preliminary 24-h study of sleep stages and associated sound levels.* Annals of Intensive Care, 2017. **7**(1).
57. Badia, P., et al., *Quality Improvement Initiative to Reduce Nighttime Noise in a Transplantation and Cellular Therapy Unit.* Biol Blood Marrow Transplant, 2019. **25**(9): p. 1844-1850.
58. Winterbottom, F.A., K. LeBlanc-Lucas, and A. Boylan, *Nurses' Influence on Patient Wellbeing: Noise Reduction and Sunshine Therapy.* Critical Care Nursing Clinics of North America, 2020. **32**(2): p. 327-334.
59. Sarkar, M., et al., *Increased Patient Satisfaction in the Postanesthesia Care Unit with the Implementation of a Controlled Noise Reduction Program.* J Perianesth Nurs, 2021. **36**(1): p. 3-7.
60. Arık, E., et al., *Prospective Randomized Study on the Effects of Improved Sleep Quality After Craniotomy on Melatonin Concentrations and Inflammatory Response in Neurosurgical Intensive Care Patients.* World Neurosurg, 2020. **140**: p. e253-e259.
61. Koçak, A.T. and S. Arslan, *The Effect of Using Eye Masks and Earplugs on Intensive Care Patients Quality of Sleep and Vital Signs.* J Neurosci Nurs, 2021. **53**(1): p. 29-33.
62. Demoule, A., et al., *Impact of earplugs and eye mask on sleep in critically ill patients: a prospective randomized study.* Crit Care, 2017. **21**(1): p. 284.
63. Carugno, M., et al., *Effects of aircraft noise on annoyance, sleep disorders, and blood pressure among adult residents near the Orio al Serio International Airport (BGY), Italy.* Med Lav, 2018. **109**(4): p. 253-263.
64. Nguyen, T.L., et al., *Community response to a step change in the aircraft noise exposure around Hanoi Noi Bai International Airport.* Journal of the Acoustical Society of America, 2018. **143**(5): p. 2901-2912.
65. Di, G., et al., *Study on Annoyance and Sleep Disturbance Induced by Combined Noises from Road Traffic and Viaduct Rail Transit.* Acoustics Australia, 2019. **47**(3): p. 229-237.
66. Thiesse, L., et al., *Transportation noise impairs cardiovascular function without altering sleep: The importance of autonomic arousals*.
67. Schmidt, F.P., et al., *The impact of aircraft noise on vascular and cardiac function in relation to noise event number - a randomized trial.* Cardiovasc Res, 2020.
68. Fields, J.M., et al., *Standardized general-purpose noise reaction questions for community noise surveys: Research and a recommendation.* Journal of Sound and Vibration, 2001. **242**(4): p. 641-679.
69. Casson, A.J., *Wearable EEG and beyond.* Biomedical Engineering Letters, 2019. **9**(1): p. 53-71.
70. Park, K.S. and S.H. Choi, *Smart technologies toward sleep monitoring at home.* Biomedical Engineering Letters, 2019. **9**(1): p. 73-85.
71. Mullington, J.M., et al., *Developing Biomarker Arrays Predicting Sleep and Circadian-Coupled Risks to Health.* Sleep, 2016. **39**(4): p. 727-36.
72. Mullington, J.M., *Please forgive our appearance while under biomarker construction.* Sleep, 2019. **42**(1).
73. Lau, E. and J.C. Wu, *Omics, Big Data, and Precision Medicine in Cardiovascular Sciences.* Circ Res, 2018. **122**(9): p. 1165-1168.