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Team 5 Noise and sleep: A review of research from 2021-2023

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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. Studies on environmental noise (transportation, wind turbine), occupational noise, and hospital noise were included. A PubMed search for titles or abstracts including "noise" and either "sleep" or "insomnia" revealed 338 papers published between 2021-2023. Titles and abstracts were screened for suitability (original research only; English language), yielding 80 articles published since the previous ICBEN review. Several themes emerged during the review; population-based studies have been performed, with some incorporating physiological measurements in the field. There has been particular interest in young populations, with several studies published for effects on infants, children, adolescents, and young adults. The effects of combined exposures, such as noise combined with air quality/pollution or artificial light, continue to gain interest. Traffic noise (aircraft, road, and rail noise) and wind turbine noise have also been investigated in several papers, both in laboratory and field studies. Several studies have investigated non-pharmacological interventions to mitigate sleep-disturbing effects of noise, including reduced traffic speed limits, noise masking, and noise-cancelling headphones. Studies using novel EEG-based indicators of sleep disturbance (K-complexes, Odds Ratio Product, power spectral density) have emerged. Many studies (n=26) related to hospital noise and patient sleep and recovery. The literature review also included one animal study. Finally, the WHO review and meta-analysis on self-reported sleep disturbance was updated to include the most recent evidence.

Keywords: Environmental noise, Sleep, Occupational noise, Pathophysiological mechanisms, Vulnerable groups, Hospital noise

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 in February 2023. Articles published between April 2021 and February 2023 were identified through a search in PubMed of article titles and/or abstracts with the search terms ("sleep" OR "insomnia") AND "noise". Titles and abstracts were screened for eligibility, with additional screening of the full text if needed. In preparing this paper in April 2023, we further updated the literature to include newly published papers of which we were aware. Original research studies on transportation, wind turbine, and hospital noise are included in this narrative review.

RESULTS

The search identified 338 articles. After initial screening, 80 relevant articles were identified. Several papers were deemed ineligible after review of the full text or because of unavailability of the full text, yielding 72 new articles to include in this review, plus three that were published after the formal literature search.

Aircraft noise

Regarding field studies assessing the effect of aircraft noise on sleep, three studies were identified in the literature search. Two of the studies assessed sleep using surveys.[4,5] Al Harthy et al conducted a study in Oman reporting a statistically significant association between noise levels around an airport and insomnia and sleep disturbances.[4] The majority of the study subjects were exposed to noise levels ranging from 55.7 to 64.24 dB L_{Aeq} dB, and 41.5% of the subjects complained about insomnia.[4] Examining the changes in community responses to aircraft noise around the Tan Son Nhat (TSN) airport near Ho Chi Min City, Trieu et al applied two community response surveys conducted 11 years apart (2008 and 2019).[5] Comparing the two survey years, relatively small changes were observed for sleep quality, although the number of operated flights and passengers had increased from 2008 to 2019. In a quasi-experimental study from New York, Wang et al investigated how changes in flight routes around LaGuardia airport impacted sleep, as well as several other health outcomes.[6] A difference-in-difference design was applied for studying the effects of noise on health in two different neighbourhoods.[6] In all age groups studied (5-64 years), aircraft noise was associated with sleep disturbances, however the association was particularly pronounced in the age group 5-17 years.[6]

Road traffic noise

Children are considered a vulnerable group for sleep disturbances from noise,[7] which makes it important to obtain knowledge on the topic in this age group. In a study among pre-adolescents around 12 years of age from Spain and the Netherlands (n= 1245),[8] residential road traffic noise (L_{den}) was statistically significantly associated with reduced total sleep time (TST) and longer wake after sleep onset (WASO), measured by actigraphy. Maternally reported sleep was, however, not associated with road traffic noise.[8]

Although polysomnography (PSG) is the gold standard for measuring sleep, it is less commonly used in field studies due to its complexity and resource requirements. A field study from Germany used PSG for investigating the impact of road traffic noise on sleep continuity (awakenings and WASO) in 40 adult suburban residents.[9] The exposure-response relationships of recorded intermittent road traffic noise in the home environment and awakenings were quantified. The results showed that the awakening probability increased with the maximum SPL and the maximum slope of the increasing SPL of a vehicle pass-by. Furthermore, a higher probability of awakening while in REM sleep than in SWS was observed.

In Zurich, Switzerland, speed reduction from 50 to 30 km/h in certain urban areas has been implemented. Brink et al [10] investigated how the speed reduction affected both traffic noise and sleep disturbances. Using data from 880 participants, Brink et al. found that the noise level had dropped by an average of 1.7 dB at night following the speed reduction. Furthermore, the study observed a significant reduction in sleep disturbances.[10]

In the context of improving environmental health in Ecuador, new legislation requires noise levels in noise hot spots to be mapped.[11] In this study, Puyana-Romero et al surveyed community responses towards noise from major roads for identifying annoyance and sleep disturbances among 244 residents living along a highway. The calculated noise levels showed that all respondents were exposed to L_{night} ≥45 dB. 19.67 % reported to be highly sleep disturbed. Compared with WHO exposure-response curves for nighttime traffic noise and percentage of highly sleep disturbed (%HSD), the exposure-response curve in the study by Puyana-Romero et al showed a steeper slope.[11]

The CNOSSOS-EU method is an emerging method for noise calculation. However, there are methodological differences in the assignment of noise exposure levels when using CNOSSOS-EU compared to previous methods, which leads to a reduced number of people exposed to high levels of noise (>55 dB L_{den} and >50 dB L_{night}). This does, in turn, reduce the number of noise annoyed and highly sleep disturbed people when using old ERFs. On the other hand, if ERFs specifically derived for the CNOSSOS-EU were to be used, the estimated adverse health effects may stay at the same level or even increase. Consequently, there is a need to develop new ERFs adjusted to CNOSSOS-EU for use in future health impact assessments.[12] In a large-scale study with 378,223 adult participants from the UK Biobank, Li et al,[13] applied a simplified version of the CNOSSOS-EU to calculate road traffic noise. After adjustment for potential confounders, nighttime road traffic noise was found to not be associated with sleep pattern, a variable defined based on sleep behaviours collected in a questionnaire (snoring, chronotype, sleep duration, excessive daytime sleepiness, insomnia).[13] A weak association was, however, observed between road traffic noise and overall sleep health.

Assessing how road traffic noise affects sleep at county level, a large-scale study from the US, applied map data on noise levels and self-reported questionnaire data on sleep deprivation (number of days not getting enough sleep). 62.9 % of the respondents were found to not get enough sleep. Furthermore, the study reported that per 10 dBA increase in average SPL (A-weighted 24-h equivalent SPL) there was a 49% increase in the odds of a person in a particular county to suffer from sleep deprivation.[14] An epidemiological study on residential road traffic noise and sleep by Gilani et al among 4,525 adult inhabitants in a town in North Kashmir, India reported that road traffic noise calculated as L_{night} at the most exposed façade was associated with symptoms of insomnia (difficulty in falling asleep, difficulty in maintaining sleep, waking up several times during the night, feeling worn out after sleep).[15] The associations were stronger among participants having their bedroom facing a road, which is consistent with a previous similar study by Evandt et al.[16] In a cross-sectional study among 822 adults living in Tehran, Iran, Monazzam et al reported no statistically significant association between the noise indicators L_{dn} and L_{night} and sleep quality.[17] However, it was found that with increasing noise annoyance, quality of sleep decreased.

Railway noise

Hahad et al performed a crossover study in which N=70 young healthy subjects slept at home and were exposed to 30 or 60 railway noise events during the night, plus a third night where no noise was introduced.[18] Noise was associated with endothelial dysfunction and impaired sleep quality in both men and women; however administration of vitamin C led to improvements in endothelial function in women but not men. Since vitamin C is an antioxidant, this suggests that mechanisms other than oxidative stress may play an important role in the pathway between chronic exposure to nocturnal noise and cardiovascular disease, especially in men.

Multiple noise sources / neighbourhood noise

Of the articles reviewed in this paper, the youngest age group studied consisted of infants in their first year of life.[19] A total of 144 infants participated in the study. The researchers found no association between transportation noise and sleep duration measured with actimetry. However, an association between noise and sleep was observed among infants with siblings. The authors attributed this finding to that a habitual noise environment, as with siblings, could modulate the relationship between noise and sleep. A study of children around the age of 11 years also reported no association between traffic noise and sleep.[20] In this study sleep was measured both using actigraphy and maternal reports.[20] The study by Perez-Crespo et al,[8] described previously road traffic section also investigated the relationship between multiple noise sources (road, rail, aircraft, industry) sleep. The results were consistent with the analyses performed with road traffic noise as the only exposure; noise was associated with sleep measured with actigraphy (TST and WASO), but not with maternally reported sleep.[8]

A study conducted by Lee et al examined the association between aircraft noise and road traffic noise and their impact on the sleep among 474 elementary school students in South Korea.[21] Sleep habits were parentally reported, and as a measure of autonomic activity, heart rate variability (HRV) was recorded. Results showed that aircraft noise was associated with night waking. Furthermore, among subjects highly sensitive to noise, aircraft noise was associated with bedtime resistance. Road traffic noise, on the other hand, was not associated with sleep. Neither noise source was associated with HRV.[21]

When looking at the effects of noise annoyance on sleep, Hanibuchi et al found that annoyance from both traffic and neighbourhood noise was associated with insomnia in a sample of 4,243 adults in Japan.[22] Utilizing the COVID-19 lockdown, Mishra et al studied the effects of the lockdown period on both noise pollution levels and sleep.[23] This study in Kanpur, India, reported both lower noise levels during lockdown as well as lower impact of noise on sleep during lockdown compared with the periods before and after.

Having measured noise over one week with noise dosimetry, Li et al reported that nighttime noise was negatively associated with time in bed, total sleep time, and awakenings.[24] Furthermore, they reported that noise sensitivity was associated with nonrestorative sleep, whereas measured noise was not. In a study including sixteen healthy sleepers, Sharman et al examined how pre-sleep cognitive arousal could affect sleep misperception (i.e. the mismatch between subjectively perceived sleep and physiologically measured sleep).[25] Subjective sleep was assessed in a questionnaire, and physiologically measured sleep was assessed with actigraphy. For the sleep measure, TST, both cognitive and somatic arousals occurring pre-sleep were negatively associated with a discrepancy in subjective and physiological sleep evaluation. A study of an African-American sample from the Jackson Heart Sleep Study reported that household environment factors, negative associations were found between noise and both self-reported sleep duration and actigraphy-based sleep efficiency.[26] A good indoor environment in dormitories is important for students' quality of life. Miao et al examined the impact of various indoor environmental quality factors, including noise, on health and well-being, there among sleep.[27] Noise exposure was found to sometimes interfere with students' rest. Additionally, the students' overall satisfaction with the acoustic environment was low.

In a study by Kim et al the association between noise and sleep was not directly assessed, however, the authors argued that sleep may be a key factor in the relationship between nighttime noise and childhood allergic disease, for which they found evidence. [28]

In a laboratory study of N=72 healthy individuals, Smith et al used a novel metric of sleep depth and stability, the Odds Ratio Product (ORP), to determine the sleep fragmenting effects of road, rail and aircraft noise.[29] Noise exposure led to event-related shifts towards wakefulness and less deep, more unstable sleep. These changes in sleep dynamically followed changes in the sound pressure level, occurring more quickly and with greater severity for rapid-onset noise (road and rail), with the most fragmented sleep occurring at the point of maximal sound level. With an increasing number of noise events, these event-related disturbances led to an overall decrease in ORP-derived sleep depth, particularly during intermediate N2 sleep, even while classical metrics of sleep structure were generally preserved.

Sleep measures objectively via polysomnography and subjectively via questionnaires are frequently in disagreement. Sharman et al investigated whether cognitive arousal, referring to high levels of worry about attaining or maintaining sleep, was related to this “sleep misperception” when exposed to nocturnal sounds typically occurring at home (e.g. traffic, car alarm, neighbour noise).[30] Thirty different 3s sounds were played at 40 dB. They found that the noise had no impact on measures of physiological sleep macrostructure or on objective or subjective total sleep time, and that there were no relationships with pre-sleep cognitive arousal. This could be because of the rather low noise levels, and/or that several of them were not disturbing for sleep. A similar study by Combertaldi et al, who found that instructing study participants to react to sounds during sleep (i.e. they were “on call”) decreased objective sleep efficiency and slow wave activity, regardless of whether they were exposed to sound (40-42 dB alarm).[31] Interestingly and perhaps counter-intuitively, being “on-call” led to reductions in event-related EEG responses. This could perhaps due to increased sleep pressure following prior sleep fragmentation as a consequence of simply being on-call.

Ebben et al examined if 1 week of using so-called “white noise devices” improved the sleep of 10 residents of New York City who had existing sleep disturbance and reported high levels of environmental noise in the bedroom.[32] When using these devices, there was a lower amount of time spent awake during the night (WASO), determined via actigraphy and reduced self-reported sleep latency. Interestingly, the improvements in WASO persisted after cessation of the white noise devices, suggesting mechanisms other than direct auditory masking of sleep-disturbing environmental sounds, possibly reduced cortical hyperactivity.

In a prospective single-subject design study of 26 emergency medicine resident physicians, Duggan et al found that using noise masking earbuds led to improvements in self-reported sleep quality and reductions in daytime sleepiness and tension.[33] These improvements were more pronounced among subjects who had worse sleep at baseline. Although noise exposure during sleep was not assessed, these data highlight a non-pharmacological individual-level intervention which may mitigate the subjective consequences of sleep disturbance by noise, regardless of noise source.

Wind turbine noise

Although the evidence of an association between wind turbine noise and sleep is inconclusive,[34] plausible potential mechanisms for this association have been presented.[35] In the field studies on wind turbine noise and sleep identified for the present review, a direct relationship between wind turbine noise and sleep was not observed, however noise annoyance from wind turbines was associated with either sleeping less deeply[36] or with reduced self-reported sleep efficiency.[37]

A laboratory study by Liebich et al found that wind turbine noise (WTN) at the upper levels of indoor values (33 dBA) did not affect objective or subjective sleep latency in young adults unexposed to WTN at home.[38] They later found no effects of low level (25 dBA) wind turbine noise on physiological sleep efficiency, sleep latency, total sleep time, WASO, or number of

awakenings.[39] Sleep diary measures were also not associated with WTN exposure. However, the same group found that exposure to short (3 min) periods of WTN during established sleep induced acute increases in delta, theta and alpha EEG power.[40] This followed an exposure-response relationship, with higher sound pressure levels inducing greater changes in EEG power. Changes in delta and theta EEG power were lower for WTN than for road traffic of the same level, but higher for alpha activity during N2 sleep. Noise also induced drops in pulse wave amplitudes, indicating sympathetic activation, although the responses were lower compared to road traffic noise.[41] These novel features of the effects of WTN on sleep go beyond classical scoring methodologies which generally find limited effects of WTN on sleep. However, the short- and long-term health consequences of these transient responses remains unclear.
Infrasound from wind turbines has been investigated for the first time. Marshall et al performed an extensive laboratory study in noise-sensitive individuals, in which 37 subjects were exposed to three days and nights of wind turbine infrasound.[42] They found no adverse effects of infrasound on any PSG-derived measures of sleep quality or fragmentation, measures of cardiovascular function, neurobehavioural performance, mental wellbeing indices, or biomarkers of stress, inflammation, or metabolic homeostasis. The absence of disturbing effects of infrasound indicates that where field studies of wind turbine noise find associations between noise exposure and disturbed sleep, those effects are likely due to the audible noise spectrum.

Hospital noise

Sleep is vital for recovery following illness or injury, but hospital noise can pose a substantial barrier to this. For instance, Foo et al found that noise was perceived as the greatest environmental disturbance, affecting 70% of N=40 patients sleeping in a ward.[43] Multiple studies have reported positive associations between hospital noise levels and reduced patient sleep quality and/or recouperation.[44-54] Objectively measured noise events >80 dB, reflecting 32-47 minutes of the period from 19:30-07:30, were associated with 35% increased risk of actigraphy-determined awakening in 69 paediatric patients (from infants to adolescents).[55] Noise events >46 dB were not associated with increased awakening risk in this hospitalised group. One study found that measured noise, specifically maximum levels and the number of events exceeding 40 dB, associated with increased sleep latency.[56] However, the sleep latency of less functionally independent patients was not significantly related to maximum noise levels, but was especially sensitive to the number of >40 dB events.

Hospital interventions to improve sleep are usually multi-component, often including earplugs, eye masks, minimising unnecessary sound such as staff conversations. Several new studies found that protocols such as these improved subjective sleep quality of patients and lead to lower noise-induced sleep disturbance.[57-61] These findings are not unequivocal however. For instance, Tonna et al found that a multicomponent intervention bundle did not significantly change overall perceived sleep quality of 314 ICU patients.[62] White noise machines were sometimes included in the interventions, and were found in one study to be helpful for 36% of this sample.[57,58] Another study found that white, pink and brown noise were all found to improve subjective sleep quality in critically ill patients.[63] There was also a study in premature infants,[64] which found that when they wore a novel hearing protection device designed to simulate the acoustic filtering of a pregnant woman's womb, there was an increase in the amount of PSG-derived sleep compared to periods when the device was not worn. Notably, when wearing the device there was also a reduction in actigraphy movements in relation to minute-by-minute sound pressure levels, indicating lower noise-induced sleep fragmentation.

As well as patients, noise can interfere with the sleep of clinicians working long night shifts, with the likelihood of nurses being able to nap for at least 90 minutes negatively associated with noise level (OR=0.88 [0.78; 0.98]).[65]

Occupational noise

It is well-known that noise exposure during the night is associated with sleep disturbances. However, occupational noise exposure during daytime is also of relevance for nighttime sleep. In the recent literature, two epidemiological studies using data from the 5th Korean Working Conditions Survey reported that noise in the workplace was associated with insomnia symptoms.[66,67] In these studies, noise exposure was subjectively defined using a 7-point scale according to the statement "noise so loud that you would have to raise you voice to talk to people". The study performed by Park et al,[66] participants observed a dose-repose relationship for the association between noise and sleep among the participants.[66] Furthermore, in a study of 380 factory workers in Turkey, using measured noise levels as the exposure, found a mean ambient noise level of 75.5 dB (SD +/-7.3). The results showed that working in environments with noise exposure of 85 dB and above was associated with poor sleep.[68]

Other noise exposures

In a sample of N=1,296 sailors on six U.S. Navy ships, 62% reported that their sleep was affected by noise in their habitation quarters.[69] Concern with noise was associated with increased severity of insomnia symptoms (higher ISI), worse habitual sleep quality (higher PSQI), and also increased actimetry-derived sleep duration in 24h. The authors explain this surprising finding of increased sleep duration by highlighting that sailors who accrue their sleep in more sleep episodes due to split shifts may report worse sleep quality, even if the total sleep duration across those episodes is longer than for sailors who have consolidated sleep.

For safety reasons, truck drivers are required to rest and sleep at certain intervals. Rocha et al investigated how the location of the resting place was associated with sleep quality and found that noise from roommates at the resting place was negatively associated with sleep quality, however noise coming from outside the room or corridors was positively associated with sleep quality.[70]

Multiple environmental factors

There are several papers that have looked at how different environmental factors in combination, including noise, may affect sleep. A study performed by Grandner et al had the purpose to develop and test the reliability and validity of a sleep environment questionnaire.[71] In the questionnaire, noise perception in the sleep environment was assessed as whether it was too noisy or too quiet. Insomnia symptoms and sleep quality was also measured and found to be associated with the physical environment, including noise. Sleepiness was, however, not associated with the physical environment. Gabinet et al investigated the combined effect of artificial light at night (ALAN) and noise on sleep.[72] In this Israeli study, both noise and sleep were measured using smartphones among 72 participants. The study found that the effects of ALAN and noise on sleep largely depended on the timing of the exposure. ALAN had the most pronounced effect if it occurred before sleep, while noise mattered most when it occurred during sleep. Furthermore, the effects of ALAN and noise amplify each other; a 14-15% reduction in sleep duration and an 8-9% reduction in sleep efficiency were observed at high ALAN-noise levels. A study from China among 1,287 elderly (>60 years) reported that exposure to light and noise in the sleep environment statistically significantly interfered with sleep.[73] Another Chinese study assessed how several environmental factors (temperature, humidity, CO_2 concentration, noise level) affected sleep during summer in 41 households.[74] Here, noise was found to be associated with poor sleep for both subjectively and objectively measured sleep. A large study by Zhong et al used participants from the California Teachers Study Cohort, including 51,562 women.[75] The authors evaluated several spatially derived environmental factors (ALAN, noise, green space, air pollution) for their effects on self-reported sleep. Among the environmental factors, noise was associated with a 5% increase in odds of having longer sleep latency (> 15 minutes) per 10 dB increase in noise level.

Bartels et al examined how both road traffic and work-related stress related to self-reported poor sleep prevalence.[76] There were only marginal effects of noise on sleep. There was also a non-significant trend for a synergetic interaction between noise and work stress, providing some indication that occupational- and lifestyle-related factors can influence individual vulnerability to noise and sleep disturbance.

Basner et al performed a cross-sectional field study to examine the effect of the bedroom environment, including noise, on sleep.[77] The sleep of 62 subjects was measured with actimetry for 2 weeks, concurrently with noise and environmental variables in the bedroom. Sleep efficiency was 3.2%-4.7% lower in the highest quintiles for exposure to fine particulate matter (PM2.5), temperature, carbon dioxide (CO2) and noise level compared to the lowest quintile, indicating increased sleep fragmentation and disturbance. Standardised effect sizes indicated associations for noise and temperature than PM2.5 or CO2. Further, there we no significant interactions, indicating that the effects of the different bedroom variables were additive, but this conclusion is limited by the statistical power of the study.

Good bedroom ventilation is needed to create a sleep-promoting environment. Lan et al found that improved ventilation resulted in lower PSG-derived measures of wakefulness and increased sleep efficiency.[78] Although these two outcomes were not affected significantly by noise, higher ventilation noise levels were associated with reductions in total sleep time, increased N1 and N2 sleep at the expense of REM sleep, and increased concentrations of salivary lysozyme in elderly participants, indicating increased antimicrobial activity. These findings indicate that noise from mechanical ventilation may compromise the sleep-promoting improvements in the bedroom air quality.

OTHER REVIEWS

In addition to this narrative review of original research, we also draw attention to an update to the WHO exposure-response curves for sleep disturbance by noise.[79] This update incorporated an additional 7 years of evidence for road, rail and air traffic.[80] Exposure-response curves were mainly unchanged for road and rail noise even with the inclusion of over 80,000 additional data for those traffic modes (sample size ~250% compared to the original review). The update included 26,000 additional responses for aircraft noise (~500% compared to original review), and showed that a higher number of people are highly sleep disturbed at high noise levels of aircraft noise compared to the original curves.

We also draw attention to a systematic review on neighbourhood environments and sleep among children and adolescents by Mayne et al,[81] who identified 15 studies on noise (perceived noise, road traffic noise, ambient outdoor noise, aircraft noise) and sleep. Eight of the studies were qualitative mentioning outdoor noise as a potential barrier to sleep. Of the seven quantitative studies, six were cross-sectional and reported associations between neighbourhood environmental noise with parentally reported poor sleep or later bedtimes. One study measured sleep with actigraphy, but no association with noise was observed. The one longitudinal study on noise and sleep did not report an association.

SUMMARY AND FUTURE PERSPECTIVES

Studies on transportation, wind turbine, occupational, and hospital noise were included in this review of research on noise and sleep since the last ICBEN conference in 2021. Studies were performed in multiple countries throughout North and South America, Europe, Asia and Australia. Latin America does however continue to be under-represented in the literature, as does Africa. The original research reviewed for this period varied in terms of design and size as both epidemiological and experimental studies were performed. Furthermore, various population groups were investigated; large population-based studies as well as samples of e.g.

students, the elderly, and women.[27,73,75,76] Several studies have also used both physiologic measures and questionnaire data, which is important for capturing different dimensions sleep processes. Regarding physiologic effects, there are some trends for utilising novel scoring methods which go beyond classical measures of sleep macro- and microstructure. In the future, studies incorporating physiological markers (such as the study of Hahad et al)[18] can offer further insights into the mechanistic pathways linking noise-induced sleep disturbance with the development of disease, especially cardiometabolic diseases. There was also variety in noise exposure assessment methods, including from noise maps of modelled outdoor levels, measured noise levels by the bed, and self-reported exposure (especially in studies of hospital noise). Among the studies on aircraft noise, community response to aircraft noise changed only a small amount over an 11-year period.[5] However, changes in flight routes was associated with sleep disturbances in affected areas around an airport.[6] It was pointed out in the last ICBEN Team 5 review that effects of WTN on sleep were inconclusive. Recent evidence does however further reveal physiologic effects on sleep,[40,41] which due to the absence of effects of infrasound can be attributed to the audible frequency ranges.[42] As recent studies showed,[66-68] exposure to noise in the workplace is also relevant for sleep, although the exposure is not happening directly during the sleep period. Regarding noise exposure assessment methods, Yli-Tuomi et al emphasised the need of new ERFs fitted to the CNOSSOS-EU methodology to be used in health impact assessments;[12] as the estimated number of both highly noise exposed to road traffic noise and sleep disturbed people will be too low when using old ERFs with CNOSSOS-EU calculations. While the majority of the research looked directly into how noise disturbs sleep, noise-reducing or –masking devices were also investigated, and generally found to improve sleep. Several studies were performed on the effects of multiple noise sources on sleep. However, due to different characteristics of various noise sources (e.g. continuous vs. intermittent) it is also of interest to determine the separate effect of each noise source in such studies.[8] Although children are considered a vulnerable group to the effects of noise on sleep,[7] studies showed differing results.[8,19-21] In studies reporting null findings, it was argued that children could be robust against the effects of noise exposure on sleep,[19,20] or that it can be due to methodological issues,[20] which warrants further exploration. Several studies assessed effects on sleep of noise in combination with other environmental mental factors e.g. with ALAN for which a study reported an amplified sleep on sleep when subjects were exposed to both noise and ALAN.[72] This touches on recent interest to broaden our knowledge beyond the effects of only one or two stressors on sleep, but determining how the myriad physical, environmental, social and internal exposures that occur throughout life combine to impact not only on sleep but all dimensions of physical and mental health and wellbeing.

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