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Effects of environmental noise on sleep

Kenneth I Hume[1], Mark Brink[2], Mathias Basner[3],

[1] Centre for Aviation, Transport and the Environment, Manchester Metropolitan University, Manchester, M1 5GD, United Kingdom

[2] ETH Zürich, D-MTEC Public and Organizational Health, WEP H17, CH-8092 Zürich, Switzerland

[3] Division of Sleep and Chronobiology, Department of Psychiatry, University of Pennsylvania Perelman School of Medicine, Philadelphia, Pennsylvania, USA

Correspondence Address:
Kenneth I Hume
Centre for Aviation, Transport and the Environment, Manchester Metropolitan University, Manchester, M1 5GD
United Kingdom

Abstract

This paper summarizes the findings from the past 3 year's research on the effects of environmental noise on sleep and identifies key future research goals. The past 3 years have seen continued interest in both short term effects of noise on sleep (arousals, awakenings), as well as epidemiological studies focusing on long term health impacts of nocturnal noise exposure. This research corroborated findings that noise events induce arousals at relatively low exposure levels, and independent of the noise source (air, road, and rail traffic, neighbors, church bells) and the environment (home, laboratory, hospital). New epidemiological studies support already existing evidence that night-time noise is likely associated with cardiovascular disease and stroke in the elderly. These studies collectively also suggest that nocturnal noise exposure may be more relevant for the genesis of cardiovascular disease than daytime noise exposure. Relative to noise policy, new effect-oriented noise protection concepts, and rating methods based on limiting awakening reactions were introduced. The publications of WHO's "Night Noise Guidelines for Europe" and "Burden of Disease from Environmental Noise" both stress the importance of nocturnal noise exposure for health and well-being. However, studies demonstrating a causal pathway that directly link noise (at ecological levels) and disturbed sleep with cardiovascular disease and/or other long term health outcomes are still missing. These studies, as well as the quantification of the impact of emerging noise sources (e.g., high speed rail, wind turbines) have been identified as the most relevant issues that should be addressed in the field on the effects of noise on sleep in the near future.

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Full Text

Introduction

It is well established that noise can disturb sleep, and if this disturbance is severe and frequent enough it can lead to significant fragmentation and sleep deprivation which seriously affects our physical and mental health. [1] In the early days of modern sleep research, there was a considerable emphasis on understanding the importance of the type and structure of sleep in terms of its electro-physiologically defined sleep stages and the nature of recovery sleep following sleep deprivation. [2] However, it is unclear how the well documented deleterious effects of these early sleep deprivation studies can be applied to environmental noise disturbed sleep, as the typical level of environmental noise is usually not severe enough to produce the same degree of sleep deprivation and/or fragmentation. [3]

Nonetheless, it has been clearly established that we can have autonomic responses to noise at low levels that do not produce wakefulness, [4] as well as responses that could be described as minor fragmentation which includes shifts to lighter sleep

stages, movement and/or brief wakefulness which are frequently associated with limb and body movement. [5] In addition, there is clear evidence that night-time noise has been associated with cardiovascular disease [6] and stroke in the elderly, [7] and that autonomic arousals habituate to a lesser degree to noise than cortical arousals. [8] What is lacking is evidence of a causal pathway that directly links noise (at ecological levels) and disturbed sleep with cardiovascular disease. A large prospective cohort study measuring (noise-induced) sleep disturbance at baseline and following subjects over several years could provide this evidence, but this type of study would be expensive and the results would not be available for a number of years.

One factor that makes it difficult to determine clear exposure–response relationships for these autonomic and minor sleep fragmentation responses to noise is that they also occur naturally in the absence of noise and any other obvious external agent. The dilemma has been how to establish an acceptable point at which the additional reactions to noise clearly and demonstrably result in health impairments. [9] Adding to the dilemma is the large number of uncontrolled non-auditory factors e.g., annoyance, work and psychosocial stress, and personal characteristics like noise sensitivity that is known to affect our sleep and reaction to noise.

Transportation Noise

The past 3 years has seen continued interest in the effect of transportation noise on sleep. This has been driven mainly by the continued and planned expansion of aviation and high speed trains, which is considered to develop faster than noise suppressing technology. The future predictions for air-travel volumes indicate considerable growth and increased noise which outweighs the reductions due to quieter jet aircraft and other noise mitigation measures. In 2006, the global population exposed to aircraft noise with 55 L DN or above was approximately 21 million people. This is expected to increase at a rate of 0.7 to 1.6% per year, while passenger traffic is expected to grow at an average rate of 4.8% per year through the year 2036. [10] The main focus of research into noise disturbed sleep over the last couple of decades has been in Europe. This has in part been a consequence of the realization of the Environmental Noise Directive (END) of the European Union which required governments to provide detailed noise maps of urban conglomerations in member states and then to produce Action Plans on the basis of these maps, which should outline how citizens living in the particularly noisy areas in the maps are going to gain relief. [11] This implies the need for quantification of the effectiveness of practical intervention measures that may be applied.

Over the past 3 years, the FAA (US) have set about developing a "Research Roadmap" for future work into "Advancing Aircraft Noise Impacts Research" with a main emphasis on sleep disturbance and annoyance caused by aircraft noise. [12] The essential aim of such research is to provide the best evidence for the formulation of legislation to regulate noise that has the potential to harm citizens. The research development process for the Noise Research Roadmap started with the formation of two small groups of experts and stakeholders in sleep disturbance and annoyance generation. This focus was broadened in 2009 at Euronoise in Edinburgh and Inter-noise in Ottawa where an International Forum on Aircraft Noise Impacts was held and further developed with Annual Research Roadmap Meetings in Washington in 2010 and 2011 (see www.fican.org/faaworkshop.html for details).

The differences in noise-induced sleep disturbance due to different transportation mode (air, road, and rail singularly and in combinations) has received considerable debate and conjecture in the literature. A recent laboratory based study has shed considerable light on the topic. [8] The authors studied 72 subjects (32 male) for 11 consecutive nights with 0, 40, 80, and 120 noise events employed in a balanced design, in terms of number of noise events, maximum sound pressure level, and equivalent noise load. The results showed that road traffic caused the most obvious changes in sleep structure and continuity whereas air and rail was considered more disturbing subjectively. This was attributed to road traffic noise events being too short to be consciously perceived by the subjects that had awoken in response to the event. The results also showed that while annoyance was greater for aircraft noise, cortical and cardiac responses during sleep were lower for air compared to road and rail traffic. A fascinating result was that most (>90%) of the noise induced awakenings merely replaced awakenings that would have occurred spontaneously, which helped to preserve sleep continuity and structure despite the noise. This suggests that within limits there is some homeostatic mechanism for internal monitoring and control of waking arousals (or maintaining sleep) that are allowed during each night's sleep.

Noise policy and legislation are most often based on average noise levels (like L DEN or L night). Obviously, a lot of information about traffic noise patterns and sound levels of individual vehicles is lost in this process. [1] A noise protection concept based on single aircraft noise events that explicitly limits the number of additional awakenings induced by aircraft noise was first published in 2006 and is used at airport Leipzig/Halle. [13] The concept has recently been adopted by Zurich airport [14] and Frankfurt airport, [15] where additional awakenings are used in the framework of noise effect indices. These indices are noise assessment instruments that express the effect of aircraft noise either as a figure that equals the amount of people that are relevantly affected by the noise, or, in the case of night noise, the total number of awakening reactions elicited. Also, more complex Markov state transition models that can be used to predict the effect of different traffic patterns on sleep structure, not just awakenings, were recently published. [16] The authors showed that high traffic volumes during the shoulder hours of the day are detrimental for

people who go to or have to go to bed either early or late (e.g., children, shift workers).

Other Environmental Noise Sources

There has been a growing interest in the negative health effects associated with other environmental noise producers, particularly wind turbines, which are becoming an increasing feature on the landscape and coastal seascapes as a result of the global drive for non-carbon energy production. [17],[18] Until now, most research into wind turbine noise effects considered annoyance, but a socio-acoustic survey including self-reported sleep disturbance due to wind turbine noise has been published recently. [19]

There are other established areas of noise-disturbed sleep research such as those concerned with assessing and improving the negative effect on health, healing, and recuperation of noise in hospitals and other health care facilities. [20] A recent laboratory study on 12 healthy adult subjects developed sleep arousal probability threshold curves for 14 sounds typical in a hospital environment. [21] The most disturbing sounds were IV pump alarms and phone "rings." For each of the common hospital noises, recommendations were provided to improve the acoustic environment and reduce the level of disturbance. Utilizing the same data set, it was found that the density of sleep spindles, a characteristic feature in the electroencephalogram of stage 2 sleep, in noise-free nights predicted arousal probability to noise stimuli in subsequent nights. [22] If replicated in other data sets, this may be the first physiologic marker of noise sensitivity, which is known to vary considerably between subjects. [23] The authors also found that EEG alpha activity, another EEG feature that is a typical sign of the wake state, immediately prior to noise stimulus application was associated with higher arousal probabilities, and may thus be a marker of immediate sleep stability. [24]

A Swiss study investigated 27 subjects living in the vicinity of churches that ring bells during the night with polysomnography for 4 consecutive nights. [25] At the same maximum sound pressure level, they found awakening probabilities to be higher relative to a similar study investigating the effects of aircraft noise on sleep. [13] The authors estimate that approximately 40 000 inhabitants in the Canton of Zurich on average experience one or more additional awakenings induced by church bell noise every night alone. [26] Thus, the overall public health impact of nocturnal church bell noise may be major, since church bell ringing during the night is a common phenomenon practiced in many countries around the world.

Epidemiologic Evidence

The epidemiologic evidence that long-term traffic noise exposure increases the incidence of cardiovascular disease has increased considerably since 2008. [6],[7],[27],[28],[29],[30] At the same time, the evidence increases that nocturnal noise exposure may be more relevant for the genesis of cardiovascular disease than daytime noise exposure. For aircraft noise, the HYENA study found a non-significant decrease in the risk of hypertension for daytime LA, eq (OR 0.928, P = 0.190), but a significant increase for L Night (1.141, P = 0.031, both per 10 dB increase). [6] Babisch et al. showed more than 10 years ago that road traffic noise exposure increases the risk of cardiovascular disease more in those who sleep with open windows or whose bedroom is oriented toward the road. [31] Lercher et al. found that the risk for hypertension increased in those who slept with open windows during the night, but it decreased in those who had sound insulation installed or where the bedroom was not facing the main road. [32] A recent Swiss study presented evidence of an adverse effect of railway noise on blood pressure, which was especially associated with night time exposure. [33] The same study also underlined the need to investigate potentially vulnerable groups, as effects of noise exposure were particularly high among persons with physician-diagnosed hypertension, cardiovascular disease, and diabetes.

Recommendations of the WHO - Europe

WHO - Europe has continued to be instrumental in driving the environmental health agenda in Europe and published the Night Noise Guidelines for Europe which summarize the deliberations of many experts and provide a clear and simple guide for planners and regulators. [34] The NNG summarize the relationship between night noise and health effects into four ranges of continuous outside sound level at night (L Night):

<30 dB - Although individual sensitivities and circumstances differ, it appears that up to this level no substantial biological effects are observed.

30-40 dB - A number of effects on sleep are observed from this range: Body movements, awakening, self-reported sleep disturbance, and arousals. The intensity of the effect depends on the nature of the source and the number of events. Vulnerable groups (e.g., children, the chronically ill and the elderly) are more susceptible. However, even in the worst cases the effects seem modest.

40-55 dB - Adverse health effects are observed among the exposed population. Many people have to adapt their lives to cope with the noise at night. Vulnerable groups are more severely affected.

>55 dB - The situation is considered increasingly dangerous for public health. Adverse health effects occur frequently, a sizeable proportion of the population is highly annoyed and sleep disturbed. There is evidence that the risk of cardiovascular disease increases.

More recently, WHO - Europe (2011) has reported on the burden of disease as a result of the growing concern of the public, environmental health agencies, and policy makers in Europe, in terms of disability-adjusted life-years (DALYs) lost due to environmental noise. [35] The findings suggest that sleep disturbance, due mainly to road traffic noise, constitutes the heaviest burden followed by annoyance which account for 903 000 and 587 000 DALYs, respectively. The other factors associated with environmental noise are ischemic heart disease (61 000 DALYs), cognitive impairment in children (45 000 DALYs) and tinnitus (22 000 DALYs). The report concludes with the estimate that at least one million healthy life years are lost every year from traffic related noise in Western Europe.

Recent Reviews and Special Issues

In 2010, there was a Special Issue of the Noise and Health journal published (12;47) devoted to noise and sleep which contained some of the papers and deliberations presented at the ICBEN-2008 conference. As a result of this publication, two points of view emerged which were reflected in the Letters to the Editor in a later issue of Noise and Health (12;49) about whether or not physiological responses to noise during sleep have meaningful health consequences that are amenable and valid for the construction of exposure–response curves. [36],[37] One realization to emerge from the debate was the difference between the European view of health, which can include mental and physical well-being, not just the absence of disease, which is basically in line with the WHO definition of health, adopted in their 1946 constitution, and the US position which tends to be more pragmatic. Elucidation of the mechanism by which noise-disturbed sleep leads to significant reduction in health is a primary goal to resolve this issue.

There have been a number of reviews of the literature in the past 3 years on the effect of noise on sleep. The BEL Report set out to estimate dose–response relationships between noise exposure and health impacts in the UK which focused on the "key" outcomes of cardiovascular effects, hypertension, and sleep disturbance. [38] However, they found that despite sleep disturbance being a well developed area with robust data, no consensus on any single dose–response relationship between noise level and sleep disturbance could be used to inform a cost-benefit analysis. Also, they concluded that no quantitative link could be established between sleep disturbance due to noise and any long term adverse health effects. But it was possible to find a robust link between noise exposure and hypertension. The authors considered that further research was needed to investigate the links between noise and air pollution and links between transient sleep disturbance and long term health effects.

Another review of aircraft noise and sleep disturbance in 2009 was carried out for the CAA (UK) and found results inconclusive and often contradictory with considerable practical design difficulties. [39] The author suggested the need for large-scale long-term epidemiological field studies that include cardiovascular and hormonal measures at various exposure sites. The study should include actigraphy and some polysomnographyfor calibration and validation, to resolve the links between environmental noise, sleep disturbance, and health.

A further review funded by the Partnership Program in the US and Canada concluded that aircraft noise can cause sleep fragmentation which can involve increases in the number and length of awakenings, reduced slow wave (SWS) and rapid eye movement (REM) sleep, and increased heart rate and blood pressure, reduced subjective sleep quality, increased sleepiness and annoyance, but only a small effect on performance next day. [40]

Outstanding issues and further research needs

There are a number of outstanding issues which need to be addressed in any further research work. First and foremost, as it is currently impossible to attribute long term health effects directly to sleep disturbance and as it takes several years for these illnesses to develop, studies demonstrating a causal pathway that directly links noise (at ecological levels) and disturbed sleep with cardiovascular disease and/or other long term health outcomes are needed. [41]

There are various methods employed in sleep recording and each has its own advantages and definition of disturbed sleep, so some appropriate combination of methods would seem the most acceptable way forward to reduce the cost and "method bias." [42]

Site and subject selection in any future field study are important as it seems plausible that a good proportion of residents near to airports or busy roads etc may represent "noise survivors" who did not avoid buying a property near to a major noise producer and individuals who have not moved away because they are able to cope with the noise. However, there is no direct evidence to date that this self-selection bias is in operation.

Age and socioeconomic status are major co-factors in considerations of noise and health and its end-points e.g., sleep disturbance, where healthy young adults tend to be generally good sleepers while the middle-aged and elderly tend to have poorer sleep with increased susceptibility to disturbance and fragmentation as a result of noise. In most countries, higher socio-economic status allows individuals to choose homes in more desirable areas which usually involve higher levels of "peace and tranquillity" and are generally able to afford higher levels of sound attenuation in city center locations.

It is hard to imagine an individual who suffers routine sleep disturbance who is also not highly annoyed with the noise source, so the strong links between annoyance and sleep disturbance need to be considered in the design and planning, in addition to annoyance reactions without associated sleep disturbance.

Someone who lives in a noisy neighbourhood and is disturbed at night by noise is likely to have a significant daytime noise load particularly at weekends, so the sleep disturbance and its long term effects may be a result of both exposures and this needs careful consideration.

The potential link between air and noise pollution is frequently mentioned but rarely studied. An exception was a study that found that exposure to residential road traffic noise was associated with a higher risk of stroke among older people (>64.5 year) after controlling for air pollution. [7]

A very recent submission from the ENNAH project to the EU provides a clear lead and summarizes what new research is needed: "New research on sleep should address the mechanisms by which noise disturbs sleep, and how noise-disturbed sleep may lead to health effects. This insight is needed to predict the impact of noise events and to evaluate the effectiveness of possible measures to reduce the impact of night-time noise exposure. There needs to be an appreciation of groups vulnerable to sleep disturbance and studies of sleep in those with chronic diseases. Future research may include assessing the effects of combined noises and combined environmental stressors on sleep. This may be carried out in extended field studies with new cost-effective methods of recording disturbance including cardiac arousals, as well as established measurement tools such as actimetry and subjective assessment." Furthermore, studies are needed to quantify the impact of emerging noise sources such as high speed rail and wind turbine noise and the impact of interventions to reduce noise.

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