Sleep disturbance due to noise: Research over the last and next five years

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INTRODUCTION

Sleep is a fundamental human behavior which is essential for development, health and well-being. Sleep displays both homeostatic and rhythmical features and its alternating pattern with wake presents one of the most obvious and essential human circadian rhythms. Sleep is a reversible process which can be readily disturbed by noise to cause a full range of perturbations from full awakening to minor unconscious autonomic effects.

It is generally accepted that the developed and developing world are becoming noisier places with eg. mobile ring tones having the ability to disturb the most tranquil place at any time of day or night. Noise pollution has been described as the 'modern unseen plague'. Humans are responsible for most of the noise that disturbs sleep in the home – a loud snoring partner is an unwelcome bed-fellow.

Noise is generally considered 'bad' but is frequently a by-product of well-accepted operations which are valued by the community at large (ie. 'good') such as most forms of modern transportation. This is similar to many controversial issues in the world today where there is need for a balance to be achieved between the potential damage that noise can cause and the benefits that accrue to many from modern transport systems. Scientist's role in such dilemmas is to assess the potential damage to health and well-being and determine the point at which unacceptable damage is likely to occur.

Part of the increase in global noise is due to continued growth of a 24h culture in most developed countries which results in more activity and noise intrusion into the night-time and sleep period. Not only is the environment becoming noisier but it seems from some annoyance data that our 'ears are becoming bigger' as we are becoming more sensitive and annoyed by noise, particularly aircraft noise. Noise can have a number of unwanted effects ie. reduces the fidelity of communication, interferes with cognitive processes, causes annoyance and complaint and disturbs sleep. Many workers in the field consider sleep disturbance to be the most detrimental to health.

This brief review will consider some fundamental issues concerning noise and sleep disturbance, outline some of the developments over the last five years and consider the continuing and emerging issues with some suggestions how research will develop in the future.

Noise and sleep disturbance

Sleep is the paramount restorative process necessary to maintain normal levels of brain and behavioral functioning, mood and well-being while awake. Sleep disturbance is important because if it is sufficiently severe it reduces our nightly recuperation which affects our waking performance as well as our health and mood. There are limited techniques available to measure the effect of sleep loss or disruption on waking activities and they are cumbersome and time consuming eg. multiple sleep la-

tency test (MSLT) and vigilance tasks. More recently there has been interest in daytime studies that highlight previous night's sleep problems eg. driving error in simulators. Besides the acute waking effects of sleep disturbance there are potential chronic additive effects of nighly noise which have been suggested to have the potential to contribute to cardiovascular disease. The HYENA study has established that aircraft noise increases the risk of hypertension.

There are both internal and external causes of sleep disturbance. Internally there are sleep pathologies eg. sleep apnea but also somatic illness eg. infections and cough as well as factors of a more psychological origin eg. anxiety and stress frequently work related. The most important external cause of sleep disturbance is due to noise pollution - we have control over many things in our home environment except for noise as we cannot switch off our hearing. There are varying reports from different countries as to what form of noise pollution in the home environment at night is the most disturbing eg. mopeds in the Netherlands but transportation noise at night is a major factor in most reports. A recent reviewer (Muzet 2007) has echoed a well known fact in 'complaint analysis' that the "psychological dimension of the expressed annoyance is highly related to the specific relationship that exists between the noise producer and receiver" in essence, your neighbor's dog barks louder than your dog!

Sleep disturbance is not a unitary concept, there is a full range of effect from full blown awakening to subtle changes in autonomic physiology and these changes are not necessarily consistent within an individual for a given level of noise stimulus as there are complex patterns of neurophysiology associated with the different EEG-defined sleep stages and the time of night. Given this complex process it is easy to see that there are various end-points that can be chosen to assess the degree of sleep disturbance. These range from measures extracted from the EEG based polysomnography, which is considered the 'gold-standard' of sleep recording and provides a direct measure of cerebral activity from which a number of macro and microstructural features can be extracted (Basner et al. 2008). In addition, actigraphy which measures limb movement, which is frequently associated with relatively major arousals in the EEG, to autonomic nervous system arousals eg. heart rate accelerations which can occur in response to noise without major EEG arousals. Other studies have employed direct behavioral action as an end-point eg. pressing a button when awoken by a noise. A number of reviewers have pointed out that this diversity of end-points has detracted from the clarity of results that can be communicated to wider audiences.

In this short paper it is impossible to fully review all the relevant work on sleep disturbance due to noise and not necessary when adequate longer reviews exist. However, it is possible to consider the main important consensus findings and understand the pressures eg. political, social and economic that are operating and what, based on current evidence, useful suggestion and pointers can be made for the future.

The World Health Organisation (WHO - European Office) have been instrumental in bringing experts together in recent years and preparing documents that have focused on establishing Night Noise Guidelines for Europe (NNG), Aircraft Noise and Health and Practical Guidance for Health Risk Assessment of Environmental Noise in Europe, which contain up to date reviews of noise and sleep disturbance and the potential risk to health, further details of full publication will be reported at ICBEN 2008. The WHO NNG summarize the relationship between night noise and health effects in the population into four ranges of continuous outside sound level at night Ln:

<30 dB - no substantial biological effects could normally be expected; 30-40dB - primary effects on sleep start to emerge and adverse effects in vulnerable groups; 40 – 55dB – sharp increase in adverse health effects while vulnerable groups become severely affected; >55dB – adverse health effects occur frequently with high percentage of the population highly annoyed.

Main developments

The fuller understanding of the effect of noise on sleep depends to a large extent on more fully understanding the fundamental questions of the nature and function of sleep. For example, the work on memory consolidation during sleep indicating the roles of SWS for explicit contents and REM for implicit contents has shown considerable advance in recent years (eg. Yoo et al. 2007). Therefore, the more we understand what undisturbed sleep does the more we will understand what deficits will be incurred when sleep is disturbed.

One direct advance in sleep research which benefits our fuller understanding of the effects of noise on sleep is work into establishing the level and nature of normal values of spontaneous arousals and perturbations that occur in sleep (Halasz et al. 2004) which allows clearer assessment and identification of what may be a significant increase due to some potential sleep disturbing factor such as noise. Also, studies directed at understanding the essential link between EEG arousals, sleep fragmentation and reduced daytime functioning (Bonnet & Arand 2007).

The most generalized disturbing noise in the urban and suburban environment, where most of the population in the developed world live, is due to transportation noise, particularly due to road, rail and specifically air traffic. This is reflected in papers submitted to ICBEN, in 2003 there were 17 papers published in the proceedings, 12 were on transportation noise of which 9 were concerned with aircraft noise. There is a similar focus in the abstracts for ICBEN 2008 with 11 papers on transportation of which 6 involve aircraft noise. Therefore similar to previous years transportation noise dominates concern and research affecting sleep.

Before the ICBEN 2003 there had been 3 major field studies (Ollerhead et al. 1992; Fidell et al. 1995; Passchier-Vermeer et al. 2002) into aircraft noise induced sleep disturbance which had used a mix of methods to determine sleep disturbance. Michaud et al. (2007) reviewed this early work, but did not include the DLR studies, and concluded that, sleep disturbance due to aircraft noise was potentially one of the most serious effects on humans. However, there was difficulty in generalizing these early findings because of differences in: individual subjects, methodological and analytical approaches and limited predictive relationships that only accounted for a small part of the variance. However, they concluded that disturbance was more likely later in the night than earlier, indoor noise recordings should be preferred to outdoor because the relationship is not always clear, a need to be aware of frequent indoor generated noises and spontaneous subject arousals.

Finally these authors warned against over simplification of these studies and to treat with caution development of regulatory policy for aircraft noise. Muzet (2007) echoed some of these findings stating that research has focused on different situations and environments and therefore suffered with variable results.

The major development over the last 5 years in this field has been the full publication of the largest and most comprehensive study carried out by Alex Samel and Mathias Basner and co-workers at the DLR-Institute of Aerospace Medicine in Germany which have provided a wealth of information on the effect of aircraft noise on sleep.

They recorded a total of 2,240 subject nights in both the laboratory and field. This database provided clear results in terms of changes in the macrostructure of sleep stages, immediate event related analysis, dose – response relationships between aircraft maximum sound pressure levels and the probability of awakening (Basner & Samel 2005). The DLR group also applied their findings directly to the difficult practical problems of noise disturbance around busy airports and developed the concept of 'noise protection zones' on the basis of sleep disturbance rather than the traditional noise contours which are based solely on acoustic criteria (Basner et al. 2006).

Continuing and emerging issues

There are many indications that the number of people exposed to transportation noise and particularly aircraft noise disturbance will increase over the next 20-30 years. There have been substantial increases in aircraft noise over the last five years. Europe has witnessed a marked increase of low cost 'budget' air operations over recent years, which has had the effect of increasing air travel and, due to limited capacity at the major airports, this market has moved to smaller regional airports. This has increased the number of flights at these traditionally 'quiet' airports and importantly they tend to have a much lower ambient noise level compared to the major airports which are usually found in larger conglomerations. Therefore the potential for noise disturbance has increased and spread considerably.

Despite the majority of major European airports being subjected to noise related capacity constraints many airports are developing wherever possible to maximize their customer throughput and maximize profit. Additionally, with the 'awakening of sleeping giants' in Asia (eg. China and India), global travel is set to rise at a considerable rate as economic prosperity and affluence is linked with industry, trade and travel. In parallel to the recent and projected increase in aircraft noise disturbance there are increases in the expectations of the quality-of-life which is seen in the heightened sensitivity and reduced tolerance in noise affected communities. The problem of aircraft noise involves a complex interaction of a number of non-acoustic factors including psychological and sociological issues. As a result there is a number of research groups investigating the non-auditory effects of noise eg. annoyance. As a consequence of this complexity that contributes to people's perceptions and response to disturbance there has been an inability of acoustic variables (eg. Leq noise contours) on their own, to satisfactorily predict annoyance and complaint due to environmental noise (Thomas et al. 2004).

A number of authors have commented on the disparity in the physiological response to noise, which is produced by an individual noise event and the sound pressure entering the ear at that moment in time, while the environmental noise is measured in Leq which averages sound energy over a given period eg. 8 hours. Residents in noise affected areas comment that the degree of disturbance is more determined by the number of loud events, not a computed average level of sound energy outside the house. Obviously the two are related but not exactly. Another fundamental problem with such technical noise metrics as descriptors is that they do not describe noise exposure patterns in ways that the general public can understand and this presents a major problem when trying to engage and conduct a meaningful dialogue with eg. airport residents (DOTARS 2003). However, it is more politically expedient to use outside noise levels and an average sound pressure level over the 8h, particularly as the European Noise Directive has theoretically furnished us with maps which indicate average sound pressure levels for different periods of the 24 hours. Never-the-less, there is a strong case for supplementary descriptors to aid communication. A recent

five year UK Government funded project OMEGA (Opportunities for meeting the environmental challenge of growth in aviation) addresses some of the above issues and operates as a knowledge transfer network that addresses the future sustainability of civil aviation.

There is a growing realisation that raw noise level in terms of decibels (dB) is a crude measure and does not adequately define the full nature of the noise stimulus. It may be possible to more thoroughly categorize transportation sounds through insights gained from the study of soundscapes and be able to more meaningfully appreciate the impact on the human listener. There has been an EU funded study (SEFA – sound engineering for aircraft – AST-CT-2003-502865) looking at aircraft's noise-producing components and how they could be modified to produce a more pleasing sound or more acceptable aircraft noise.

In terms of methodological issues concerning noise and sleep disturbance: EEG-based studies have remained the gold-standard as sleep is a phenomenon uniquely associated with the brain whose gross activity is directly measured by EEG and REM sleep needs EOG and EMG additionally for correct classification; ECG and other autonomic measures are useful for determining cardiovascular responses to noise stimuli and can provide insights into disease aetiology; Actimetry is a convenient adjunct, cost effective, easy to use and analyse but its interpretation is not always precisely clear; signalled awakening again provide a simple and convenient technique but can be prone to problems of poor compliance; sleep logs and questionnaires provide useful subjective data and complaints have motivation issues but are key drivers in the political arena. A new technique is being developed that would be an asset to the field of noise a sleep disturbance which is an ECG-based algorithm for the automatic identification of autonomic activations associated with cortical arousals, which saves considerable human analysis time and aids consistency and objectivity (Basner et al. 2007).

Field research into the effect of noise on sleep is essential for realism while laboratory studies can deliver appropriate high levels of control of confounding variables that are usually present in the field. Therefore both these types of study are important. Early field studies showed much less sleep disturbance than what was predicted from laboratory results. This has been explained by a lack of habituation in the laboratory setting (Hume & Whitehead 2003).

Despite all the work in this area there is still uncertainty as to the long term health consequences of night-time noise disturbance on exposed populations. Some authors have commented on the lack of an epidemiological study that shows a causal link between noise, sleep disturbance (aircraft) and long-term illness. So, there is still a need for large scale field studies with representative samples of the population to investigate the association between night-time aircraft noise exposure and cardiovascular disease.

Looking to the future, there is an exciting development to greatly increase our potential for accessing considerable field data due to the greatly increasing number of households that are linked by broadband internet services and WiFi in developed countries eg. Western Europe. This could allow residents from wide areas eg. around airports, to pass digital information, when they would nomally be off-line eg. in bed at night, to a central receiver and analysis point which could also collect co-terminus noise and flight data. There would have to be some development and suitable interfacing to transmit eg. electrophysiological data, actimetry and simple subject signal-

ling. The ECG signal presents itself as a robust and easily recorded signal that would be ideal for this system and in combination with the algorithm work indicated above.

Premature awakening can be an extremely annoying experience and frequently complained about. Community complaints and annoyance have been key drivers in the political noise arena. There has been some work (Hume et al. 2003) to systematically analyse complaints and annoyance in high noise areas to better understand these issues. The basic rationale is that the data is provided free, provides a rapid feedback and reflects regional/area annoyance. Thus providing a better understanding of how noise affects individuals and provides evidence for noise producers (aircraft, airlines and airports) to modify operating systems and aircraft movement patterns to reduce noise exposure in affected areas.

The problems of road, rail and air traffic have become a major issue at the local level with noise and air quality and at the global level with carbon emission and global warming (Thomas et al. 2004). There has been significant work completed on combined transportation modes and how additive the disturbance which is addressed in papers at ICBEN 2008. In the future the combined effects of noise exposure with other agents eg. poor local air quality on health needs to be addressed.

One issue which has considerable potential to add to the noise burden and disturb sleep has developed at a much more rapid pace than was foreseen five years ago are wind turbines as alternative power sources to carbon fuels. Fortunately up until now these wind-farms have been sited in very exposed locations on the tops of mountains and at sea ie. well away from the main areas of human habitation, but in the UK there is a very recent political move to encourage individual households to make use of this technology and install roof top turbines which will be close to bedrooms. This could be a very contentious issue, and one in which sleep researchers may well become involved.

The study of the increased risk in vulnerable groups including young, old, sleep disorder patients, shift workers is frequently mentioned but rarely studied. It is surprising that given major airports operate 24h for 7 days a week and employ considerable numbers of local staff who have to work night shifts that this clearly highly vulnerable group, who one would surmise have disturbed sleep, have not been studied in depth, to my knowledge.

Looking to the future and the increased longevity of westernized cultures due to improved medication and health care, there are predictions that the proportion of the elderly in society will grow significantly over the next 30 years. This suggests another vulnerable group will grow ie. Hospital patients, Nursing and Care Home residents. There is a literature based around noise and sleep problems associated with hospitalization, acute/intensive care units and institutionalization particularly in old age homes. Koch et al. (2006) found that adopting a multidisciplinary approach combining noise reduction, promotion of daytime activity and reduction of night time nursing care were the most effective means of promoting sleep, while the long term use of sedatives is questionable practice and overuse reduces the quality of life of older people. As we all get older it is in our interest to help provide the knowledge to aid sleep and improve the quality of wakefulness in the elderly.

A number of authors have indicated another vulnerable group who are also affected by sleeping at vulnerable times near to airports and that is children who are in bed during the ‘shoulder hours’ of airport operations which is the hour or so before and after the night curfew restrictions are in force. This is a time of increased aircraft mo-

vements and it is typically a time when children are in bed in the evening and morning.

These and many other sleep and noise disturbance issues would benefit from properly funded, planned and executed research studies over the next five years.

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