Environmental Research and Consultancy Department

ERCD REPORT 0907

Environmental Noise and Health: A Review

K Jones

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Summary

This review provides an overview of literature in the field of noise and health. It focuses on transportation noise, particularly aircraft noise and looks at the possible effects on health to include annoyance and psychological health, cardiovascular and physiological health, performance, and the effects of noise on children. Suggestions for future research areas are given.

February 2010

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Glossary of Acoustical Terms

dBA	Levels on a decibel scale of noise measured using a frequency dependent weighting, which approximates the characteristics of human hearing. These are referred to as A-weighted sound levels; which are widely used for noise assessment purposes.
$Leq_{(time\ period)}$	Equivalent Continuous Noise Level - a measure of average noise exposure over a defined time period.
L_pAF_{max}	A-weighted maximum sound pressure level (used in Norway and Sweden for indoor sound conditions).
Lmax	The maximum instantaneous noise level that occurs during a noise event.
NGI	Noise Gap Index – a measure that incorporates the characteristics of background environmental noise
SEL	Sound Exposure Level in dBA, a measure of noise event level, which accounts for both the duration and intensity of noise.

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1. Executive Summary

1.1 A literature review was undertaken of the scientific knowledge on the subject of 'environmental noise and health', with particular reference to aircraft noise. The World Health Organisation Guidelines for Community Noise (1999) were taken as the basis for the review, and a literature search was carried out for key papers published after the WHO Guidelines and for review papers published since the late 1990s. The WHO Night Noise Guidelines for Europe, published in October 2009 are also referred to in terms of recommended night noise limits and health effects.

1.2 The report focuses on the non-auditory effects of environmental noise and presents a summary of the scientific knowledge of noise and health under the following categories:

- Annoyance.
- Mental Health.
- Cardiovascular and Physiological Effects.
- Performance.
- Night-time Effects.
- Noise and Children.
- Foetal Effects.

1.3 It is concluded that the strength of evidence for the various non-auditory effects being associated with exposure to environmental noise is as follows:

- **Annoyance**
  Across the scientific literature it is agreed that there is sufficient evidence for environmental noise (and specifically aircraft noise) causing annoyance in those exposed.

- **Mental Health**
  Reviewers generally consider that the evidence for mental health effects is inconclusive or limited. There seems to be a trend emerging of some evidence for mental health symptoms (e.g. depression, anxiety) but not of more severe health problems such as clinically defined psychiatric disorder.

- **Cardiovascular and Physiological**
  In terms of cardiovascular impact there are mixed conclusions from the various reviews and papers on the evidence for effects. Some reviewers consider that there is sufficient evidence, others that the evidence does not convincingly demonstrate an association. Based on existing evidence, it is possible that exposure to aircraft noise may be a risk factor for cardiovascular disease and all would agree that further research is needed to examine the impact of noise on cardiovascular health.

  The scientific literature generally finds that the evidence for long-term impact on stress hormone levels is inconclusive or limited.

- **Performance (adults)**
  There is a lack of data on the impact of environmental noise on the performance of adults and no firm conclusions can be drawn.

- **Night-time Effects**
  Across the scientific literature it is agreed that above a certain threshold, environmental noise can cause awakening, and at levels significantly lower, it can also induce sleep stage changes. The threshold level above which effects are found remains a controversial point. There also seems to be general consensus that environmental noise can affect subjective sleep quality, mood the next day and has an acute impact on heart rate. However, as yet, there appears to be no strong/consistent scientific evidence of chronic objective effects (e.g. on stress hormone levels or immune system) or performance the next day.

- **Noise and Children**
  There is a growing body of literature on the impact of aircraft noise on children's health. Across the literature the evidence for the effects of noise exposure on child health is strongest for cognitive effects (particularly reading). Some studies have found that chronically noise exposed children have raised levels of stress, increased blood pressure and mental health effects; however there is still insufficient data to provide unequivocal evidence of such effects.

- **Foetal Effects**
  There has been only very limited research on the effects of environmental noise on foetuses; there is no strong evidence for any effects but it is not possible to draw any firm conclusions.

1.4 Noise level thresholds for health effects, from the WHO Guidelines and two other reviews are presented. It is concluded that agreement upon threshold noise levels, which assure effective protection of the health of the population from aircraft noise, remains controversial; this is particularly true for protection of rest and sleep at night.

2. Introduction

2.1 A literature review was undertaken of the scientific knowledge on the subject of 'environmental noise and health', with particular reference to aircraft noise. The World Health Organisation Guidelines for Community Noise ('WHO Guidelines' 1999)[1] were taken as the basis for the review, and a literature search was carried out for key papers published after the WHO Guidelines and for review papers published since the late 1990s.

2.2 A number of review papers are referred to repeatedly throughout this report, these are:

- Health Council of the Netherlands (1999). Public Health Impact of Large Airports. ('HNC Review')[2]
- Health Canada (2002). Noise from Civilian Aircraft in the Vicinity of Airports, Implications for Human Health - Noise, Stress and Cardiovascular disease. ('HC review')[3]
- enHealth Council Australia (2004). The Health Effects of Environmental Noise - Other than Hearing Loss. ('ECA Review')[4]
- Various reviews undertaken by Stansfeld and co-workers[5-7]

2.3 Two papers have recently been published in this area; the first was commissioned by the Department for Environment, Food and Rural Affairs (Defra) on behalf of their Interdepartmental Group on Cost and Benefit (IGCB) into an estimation of the dose-response relationship between noise exposure and health effects; the second is a Health Protection Agency (HPA) report entitled Environmental noise and health in the UK.

2.4 The Defra publication (2009)[8] is authored by Bernard Berry and Ian Flindell, and comprises four main aims:

- To identify a comprehensive list of potential adverse health impacts from noise and review the current state of evidence for each of the impacts;
- Where a robust evidence base exists, to recommend quantitative links (dose-response functions) for the impacts of noise on health which could be applied in the UK;
- Identify any emerging adverse health impacts that should be kept under review for future consideration in evaluation; and
- Identify any structural challenges to developing and maintaining strong quantitative links between noise and health outcomes.

The full report is available on Defra's website, although some of the main conclusions will be referred to in this report.

2.5 The HPA report (2009)[9] was produced in response to increasing public concern about possible adverse effects of noise on health. It was prepared by an ad hoc group of experts at the request of the Department of Health and funded by the Defra. As before, this report is available on the HPA website. This report will be referred to where relevant.

2.6 The WHO Night Noise Guidelines for Europe[101] (NNG) were published in October 2009. This document was presented as an extension to the WHO Guidelines for Community Noise document from 1999. The aim of the Night Noise Guidelines (2009) was to present conclusions from the WHO working group responsible for preparing guidelines to exposure to noise during sleep. These guidelines use both direct evidence concerning the effects of night noise and health, and also indirect evidence relating to the effects of noise on sleep and the relationship between sleep and health, as their basis.

3. Health Effects – Definition and Scope of Review

3.1 The World Health Organisation (WHO, 1968)[10] defines health as follows:

> *"Health is not merely the absence of disease or infirmity but is a positive state of physical, mental and social well-being."*

This broad definition has been taken as the basis for including a review of various effects within this report.

3.2 It is universally accepted that exposure to high noise levels can induce hearing impairment, however at the levels of environmental noise exposure around civilian airports hearing loss in unlikely[11-15]. This report therefore focuses on the non-auditory health effects of environmental noise, that is:

> *"All those effects on health and well-being that are caused by exposure to noise, with the exclusion of effects on the hearing organ and the effects which are due to the masking of auditory information (i.e. communication problems)"*[16]

3.3 This report presents a summary of the scientific knowledge of noise and health under the following categories:

- Annoyance.
- Mental Health.
- Cardiovascular and Physiological Effects.
- Performance.
- Night-time Effects.
- Noise and Children.
- Foetal Effects.

3.4 Some might not consider annoyance and impact on performance to be health effects, but on the basis of the WHO (1968) definition they are included. In addition, annoyance may be an important mediator in causing other health effects such as cardiovascular or stress responses. Figure 1 illustrates the possible pathways for effects (i.e. direct physiological effect or effect mediated by annoyance). The relative contributions of the 'direct' and 'mediated' pathways have not been fully established.

3.5 The WHO Guidelines (1999, 2009) note that vulnerable people (e.g. people that are ill, old, depressed, foetuses, babies and young children, shift workers) may be less able to cope with the impacts of noise exposure and they may be at greater risk of harmful effects. Generally, there is little scientific research focused on these vulnerable groups. An exception to this is the research of the effects of environmental noise on children; a body of scientific literature specifically on the effects of aircraft noise on children is emerging – this is reviewed in Section 3.6. The limited evidence on foetal effects presented in various reviews is also summarised in Section 3.7.

3.6 The literature on the non-auditory health effects of environmental noise is extensive; this review does not aim to give an in-depth assessment of the nuances of the scientific work in this field, but to provide a succinct overview of the current research in this area.

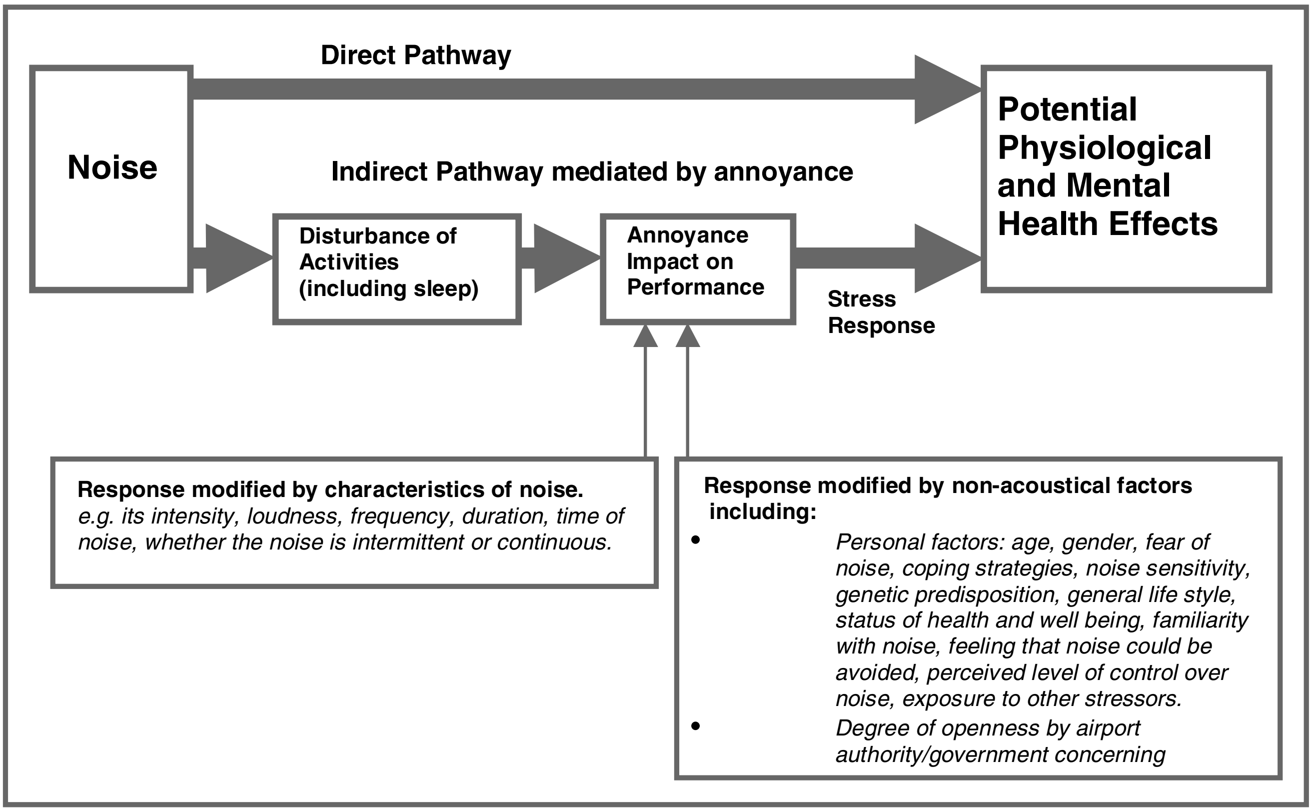

Figure 1: Possible Pathways for Effects of Environmental Noise on Non-Auditory Health

4. Non Auditory Health Effects

4.1 Annoyance

Background and WHO Guidelines

4.1.1 The most widespread and well documented subjective response to noise is annoyance; which can be defined as a feeling of resentment, displeasure, discomfort, dissatisfaction or offence which occurs when noise interferes with thoughts, feelings or activities. The annoyance of populations exposed to environmental noise varies not only with the acoustical characteristics of the noise, but also with a range of non-acoustical factors of social, psychological or economic nature; Figure 1 gives examples of non-acoustical factors which may modify the response of individuals.

4.1.2 It is well established that exposure to aircraft noise causes annoyance; a widely quoted relationship is the Schultz curve (Schultz, 1978)[17] . The Schultz curve is a graph of percentage highly annoyed against noise exposure level; it was based on data from numerous social survey studies of public reactions to transport noise. Since 1978 there have been a number of subsequent extensions and updates of the original Schultz work[18].

4.1.3 The WHO Guidelines note that equal levels of different noises can cause different magnitudes of annoyance. For example, a synthesis by Miedema and Vos (1998)[19] building further on the Schultz curve approach, of data for three types of transport noise (road, air, and railway) shows that aircraft noise produced a stronger annoyance response than road traffic and that the annoyance response to rail noise was less than for road traffic.

4.1.4 Stansfeld (2003)[20] postulated that noise exposure creates annoyance, which then leads on to more serious psychological effects. This pathway remains unconfirmed – rather it seems that noise causes annoyance, and independently mental ill health also increases annoyance.

4.1.5 Since the WHO Guidelines (1999) were published there have been further studies of annoyance from transport noise[21,22] – these studies provide new data on specific local circumstances and contribute to the database that can be used for developing dose response curves. In addition, Miedema (2001)[23] reanalysed the available international data on transport noise and annoyance (a total of 45 studies including 19 studies on aircraft noise) and produced revised curves for the relationships for the association between noise from road, rail and aircraft and annoyance.

4.1.6 A recent analysis (van Kamp, 2004)[24] examined the role of noise sensitivity with regards to aircraft noise and annoyance using data from studies undertaken around international airports in Amsterdam, Sydney and London. The analysis supported previous findings, showing that noise sensitivity is an independent predictor of the level of annoyance.

4.1.7 A Norwegian study in 2007 (Aasvang et al, 2007)[25] looked at annoyance and self-reported sleep disturbance due to radiated noise from railway tunnels (N = 521). Railway noise propagates through the structures of nearby buildings, emitting low frequency, or “rumble” noise referred to as structurally radiated noise. 278 buildings were selected that were exposed to structurally radiated noise from railway traffic in rock-tunnels.

4.1.8 The maximum radiated sound level L_pAF_{max} was used as the exposure variable. Noise calculations were based on geographical maps, additional information from the questionnaire on ground conditions, type of dwelling, and measurements were made for the bedroom as well as for the lowest level in the dwelling connected to the ground. L_pAF_{max} in the bedroom ranged between 23.9 and 42.8dB, and the number of freight train pass-bys per week was 40 to 106, with 40-50% scheduled to pass during the night (2300-0700). A quarter of respondents were annoyed by structurally radiated noise, and most were slightly (19.7%) or moderately (4.5%) annoyed. Noise/rumbling from the tunnel was given as a reason for problems falling asleep in 3% of respondents, and awakenings in 4%. In addition to the noise level, other significant effects on annoyance from structure borne noise were the number of train pass-bys, respondent age, and whether the dwelling had sound insulated windows. Younger people were more annoyed than older people, and those who lived in houses with sound insulated windows were more annoyed than those without insulation.

4.1.9 There was a significant correlation between subjective reactions to noise and the level of structure borne noise from railway tunnels. At L_pAF_{max} = 32dB inside homes, 20% were slightly or more than slightly annoyed, and 4% were moderately or more than moderately annoyed. These results supported the pre-existing assumption in the Norwegian Standard that up to 20% of the exposed population are disturbed by noise at this level, and support the Norwegian noise limit LpAFmax = 32dB of structure borne noise from tunnels.

4.1.10 A recent study examined whether personality traits such as habitual anxiety level, mirrored annoyance ratings for noise, air pollution and other environmental factors (Persson *et al,* 2007*)*[26]. A cross-sectional public health survey was conducted on 2856 respondents. The two most prevalent complaints were annoyance due to traffic noise and sounds from neighbours, reported by approximately 8% of participants. Logistic regression analysis showed that continuous trait anxiety as a predictor had positive associations with ratings of annoyance from total traffic noise, neighbour noise, ventilation noise, exhaust fumes from traffic, sounds from other installations, and vibrations from traffic. The authors suggested that caution should be exercised when using annoyance reports either as a surrogate measure for environmental exposure on the individual-level in epidemiologic studies, or when studying the moderating effects of annoyance on health outcomes.

4.1.11 Öhrström *et al* (2007)[27] investigated annoyance due to single and combined sound exposure from railway and road traffic. A socio-economic survey was conducted on 1953 participants, aged between 18-75 years in residential areas of Gothenburg, Sweden exposed to road and rail noise. The sound levels ranged from $L_{Aeq,}$ 24h 45-72dB. In areas exposed to both railway and traffic noise, the proportion of people annoyed by the total noise environment was significantly higher than in areas with one dominant noise source, with the same total sound exposure. The interaction was significant from 59dB and increased gradually with higher sound levels. The authors suggested that the effects of total sound exposure should be considered in risk assessments and noise mitigation activities.

4.1.12 Miedema (2007)[28] proposed a model of environmental noise disturbance as a stressor, impacting on behaviour (communication, concentration) and desired state (sleep and relaxation), with the ability to cope with such disturbance being important for health and well-being. The effects of noise depend on acoustical characteristics of the noise, such as loudness, time, pattern, and on aspects of the noise situation that may involve cognitive processing, such as expectations regarding the future development of the noise exposure, lack of short-term predictability, and a feeling of a lack of control over the source of the noise. Miedema suggests that the model (Figure 2) involves four routes through which noise exerts its primary influence.

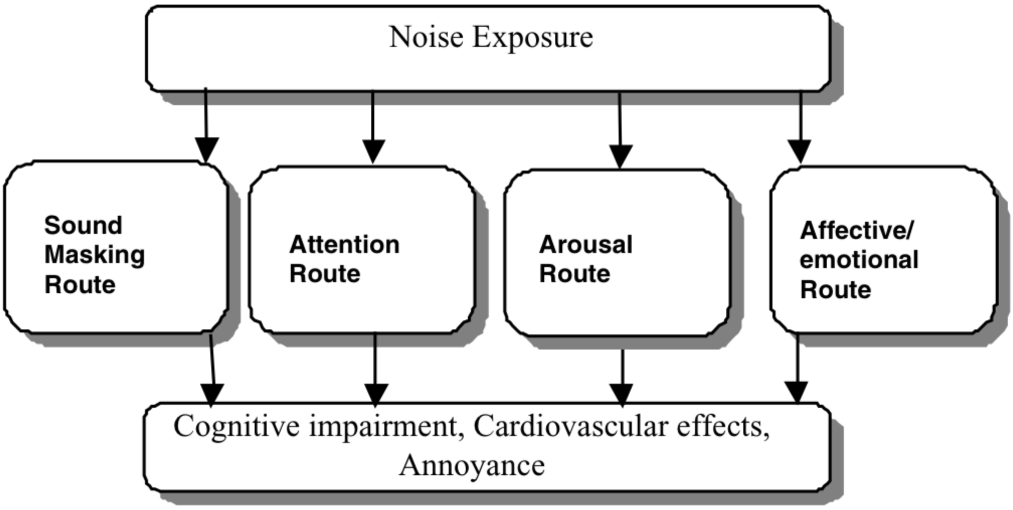

Figure 2: *Taken from Miedema (2007) illustrating the four pathways through which the effects of noise are mediated.*

Sound masking Route

This route reduces the comprehension of speech and masks speech, signals, music or natural sounds. International standard for the assessment of speech communication say that one-to-one conversation requires that the noise level does not exceed 41dBA. At a distance of 4m e.g. round a table or in a group, the noise must not exceed 29dBA. These are very rarely achieved in urban areas and imply that the effects of environmental noise on communication are ubiquitous, especially in cities.

Attention Route

Noise can negatively affect processes requiring attention. The effect of noise is probably most deleterious when impacting on working memory, and has been found to depend on the priority and difficulty of the memory task, and type of sound. Millar (1979) indicated that it is the rehearsal of the items in working memory that is negatively affected by noise. If noise detracts from rehearsal it can have negative effects on the ability to derive implications and restructure information into more meaningful clusters.

Arousal Route: Sleep

In field studies it has been found that the noise of a single event can cause instantaneous effects such as: extra motility, change in sleep state and EEG arousals, momentary changes in heart rate, and conscious awakening. The exposure-response relationship for conscious awakening has been assessed for civil aircraft (Passchier-Vermeer, 2003). Noise is described not by max sound level during the passage, but the total sound energy of the noise event (SEL). The effects of noise on sleep have low thresholds and the exposure-effect relationships increase monotonically. Noise is likely to be a dominant factor relating to sleep problems. More often it will cause a limited reduction in sleep quality that may not always be observed by the individual. Such noise-induced reductions of sleep quality may add to major causes of sleep problems that also appear to be mediated by increased arousal, such as social stress, medical stress, circadian stress and other environmental factors.

Affective-emotional route: Fear and anger

As a result of noise affecting sleep, concentration, communication etc. this frustration may lead to irritation or anger reactions. People high in trait anger may be more likely to show stronger emotional reactions when noise disturbs them. Fear can also be elicited with noise if it is associated with danger that threatens the individual. In this context it may be the worry of being in close proximity to an airport and therefore the concern over accidents that may induce fear, along with self-reported sensitivity to noise.

4.1.13 Miedema concludes that through masking, noise reduces comprehension, and through its effect on attention, noise affects the mental processing of information e.g. in reading. Through its effect on arousal, noise disturbs sleep, which may lead to fatigue, decreased performance, and depressed mood. Also, it may elicit emotional reactions when it interferes with behaviour or a desired state and may act as a stressor, or when it is associated with fear (aircraft noise). Such primary effects may in the long-term lead to annoyance, cognitive impairment, and/or cardiovascular effects. Chronic stress is also likely to be important in some long-term effects, in particular cardiovascular effects.

4.1.14 Background noise has also been found to have an effect on annoyance. Lim *et al* (2008)[29] reported that the results from a social survey administered to people living close to noise measurement sites around airports in Korea (n = 753) indicated that annoyance responses in low background noise areas were much higher than those in high background noise areas, even though the aircraft noise levels were the same.

4.1.15 A recent study conducted in Canada (Michaud *et al,* 2008)[30] evaluated road traffic annoyance in relation to activity interference, subject concerns about noise, and self-reported distance to a major road. The results indicated that respondents highly annoyed by traffic noise were significantly more likely to perceive annoyance to negatively impact health, live closer to a busy road, and report that traffic noise often interfered with daily activities. The high noise annoyance consistently correlated with frequent interference of activities, and reducing noise at night, between 2200-0700 was found to be more important than during the rest of the day.

4.1.16 Noise and airport-related pollution was assessed around La Guardia Airport in New York (Cohen *et al*, 2008)[31]. Airborne particulate matter was measured to determine the difference in concentrations in homes upwind and downwind of the airport, alongside 24-hr noise measurements in twelve homes near the airport. The impact of noise was assessed but a Community Wellness and Health Promotion Survey. Residents living near the airport were exposed to noise levels up to four times greater than those experienced by residents in a quiet, comparison home. More than 55% of people living within the flight path were bothered by aircraft noise and 63% by traffic noise, which were significantly higher percentages than those residents in the non-flight area. Particulate matter concentrations were higher during active airport operating hours than during non-operating hours, and the percent increase varied inversely with distance from the airport. The authors concluded that the combination of air pollution, aircraft noise and road traffic noise are major contributing factors to elevated annoyance levels in residents living near to airports.

4.1.17 Children's annoyance reactions to aircraft and road traffic noise have also been studied (van Kempen *et al*, 2009)[32]. Annoyance in children has rarely been studied, and the aim of this work was to investigate annoyance reactions and exposure-response relationships to aircraft and road noise in both home and school environments. Data from the Road Traffic and Aircraft Noise Exposure and Children's cognition and Health (RANCH) study was used, with a secondary aim to compare children's annoyance reactions with those of their parents. Both parents and children's reactions were measured using self-administered questionnaires. The study was done on 2844 children, aged 9-11 from primary schools in areas surrounding Heathrow, Schiphol and Madrid-Barajas airports. Aircraft noise exposure at home and school was significantly related to severe annoyance, in both cases where the noise exposure from aircraft was higher, the proportion of severely annoyed children was higher also. At school, the percentage severely annoyed children was predicted to increase from 5% at 50dBA($L_{eq0700\text{-}2300}$) to about 12% at 60dB($L_{eq0700\text{-}2300}$). At home these figures were 7% and 15% respectively. Road traffic noise at school was also significantly related to severe annoyance, with the percentage severely annoyed children predicted to increase from 4% at 50dB($L_{eq0700\text{-}2300}$) to about 6% at 60dB ($L_{eq0700\text{-}2300}$). The association between annoyance and aircraft noise is stronger in children than road noise, probably due to the intensity, variability and unpredictability of aircraft noise in comparison to road noise. Children's annoyance reactions were found to be comparable to their parent's reactions, but with children having lower response frequencies of severe annoyance than their parents at higher noise levels of 55dB and above.

4.1.18 The HPA report[9] includes a section on annoyance, and the difficulties associated with analysing annoyance responses. The conclusions from this report were that generally the risk and strength of annoyance increases with the degree of sound level exposure, and such a relationship can be expressed mathematically and graphically. The authors suggest that dose-response curves could be used for policy development, but they need to be studied closely due to the amount of scatter of individual responses occurring around the average response for any specific sound level. They caution that the reasons behind such variation are not yet well understood and that the slope of dose-response relationships may be unstable due to possible change in annoyance reactions. The authors conclude that repeated surveys may still be required to establish reliable dose-response annoyance curves. Reference is made to the Attitudes to Noise from Aviation Sources in England (ANASE) study, and that although this report suggested that more people are now annoyed than in 1982 when the Aircraft Noise Index Study (ANIS) was conducted, the authors refer to the differences in opinion between the peer reviewers (Havelock and Turner) who counselled against using the ANASE results for policy development, and the study team. The authors highlight this as an example of the difficulties that occur when trying to produce a reliable dose-response curve for aircraft noise and annoyance.

4.1.19 There was nothing substantive mentioned in relation to the ANASE annoyance results in the Defra report[8].

4.2 Mental Health Effects

Background and WHO Guidelines

4.2.1 Over the last 30 years the association between environmental noise and mental health has been investigated using a variety of outcomes, including individual symptoms (such as headaches, anxiety, irritability, and depressiveness), psychiatric hospital admission rates, and psychotropic drug use. The WHO Guidelines (1999) consider that the findings on mental health and environmental noise are inconclusive.

Other Research

4.2.2 In a review of the literature on environmental noise and mental health Stansfeld (2000)[33] concluded that current evidence does seem to suggest that environmental noise exposure, especially at higher levels, is related to mental health symptoms (such as depression) and possibly raised anxiety and consumption of sedative medication, but there is little evidence of more severe health problems such as clinically definable psychiatric disorder. For example (examples taken from Stansfeld's Review):

- A questionnaire study of 1053 residents living around Kadena military airport in Japan found an association between the highest noise exposure group and higher scores of depressiveness and neurosis[34]
- In a British study of 7540 people exposed to road traffic noise, it was found that the noise level was weakly associated with a mental health symptoms scale[35]
- A study of the impact of traffic noise (undertaken in Caerphilly) found that there was no association between road traffic noise and minor psychiatric disorder. However, there was a small non-linear association of noise with increased anxiety scores[36]
- A Health Impact Assessment around Schiphol Airport suggested that the use of non-prescribed sleep medication or sedatives was associated with aircraft noise exposure during the late evening, but not with exposure during the night. Vitality related health complaints such as tiredness and headache were associated with aircraft noise, whereas most other physical complaints were not[37]

4.2.3 Meister (2000)[38] reports on a questionnaire based survey (among 2001 respondents living in Minnesota, USA) to assess the impact of commercial aircraft noise on human health. Four of the neighbourhoods in the survey were exposed to aircraft noise and two non-exposed control communities were also included. Meister found:

- All general health measures were significantly worse for the neighbourhoods exposed to aircraft noise than for the controls – the greater the noise levels the worse the health measures were.
- Mental health scores in neighbourhoods exposed to noise were lower than the scores in the control neighbourhoods (higher score implies more positive health status).
- A sense of vitality reduced among those exposed to aircraft noise compared with those not exposed.

- Stress levels were higher among those exposed to aircraft noise; as stress increased mental health and a sense of vitality decreased.

4.2.4 Stansfeld (2000)[6] reports that studies from the 1970s and 1980s found that a high percentage of people reported headaches, restless nights and being tense and edgy in high noise areas. However, an explicit link between aircraft noise and symptoms in these studies raises the possibility of a bias towards over-reporting, due to personal attitudes towards aircraft noise. A study around three Swiss airports, which did not mention that the study was related to aircraft noise, did not find any association between the level of aircraft noise exposure and symptoms.

4.2.5 Evidence that exposure to aircraft noise is associated with higher psychiatric admission rates is mixed. Early studies (in the 1970s) around Heathrow and Los Angeles Airports found weak associations between the level of aircraft noise and psychiatric hospital admissions in the general population[39]. These studies have been criticised on methodological grounds and further comprehensive studies have found, at most, a moderating rather than a causal role for noise on hospital admission rates. However, Kryter (1990)[40] found an association between aircraft noise and psychiatric hospital admission rates in a re-analysis of data accepting admissions from around Heathrow Airport.

4.2.6 Researchers suggest that it may be that certain groups are more vulnerable to noise in the mental health context – particularly, children, the elderly and people with pre-existing illness, especially depression.

4.2.7 The Defra and HPA reports did not conclude that there is sufficient evidence for a reliable dose-response relationship between environmental noise and psychological health, and therefore suggest that this is an area that requires further investigation before any conclusions can be drawn.

4.2.8 The WHO NNG[101] (2009) concludes that evidence does suggest that environmental noise exposure at higher levels is related to mental health symptoms and possibly raised anxiety, but there is little evidence that it has more serious effects. There is not strong evidence for the association between noise exposure and mental ill health, except perhaps above 70dBA L_{eq}. The document highlights that as most studies have examined the effects of daytime noise on mental health, it cannot be ruled out that night-time noise may have effects on mental health at lower levels than daytime noise.

4.3 Cardiovascular and Physiological Effects

Background and WHO Guidelines

4.3.1 Noise can elicit a stress response in the body in the same way as other stressors. The normal stress response is a coping mechanism that occurs when the brain perceives a threat. Acute noise exposures activate the autonomic and hormonal systems, leading to temporary changes such as increased blood pressure, increased heart rate and secretion of stress hormones. Normally, these return to baseline levels when the noise ends or the person adapts. However, prolonged exposure to noise may have the potential, in susceptible individuals, to cause chronic physiological effects such as hypertension, ischaemic heart disease (IHD) and elevated stress hormone levels. Sustained elevated hormone levels may affect the functional integrity of bodily organs and tissues.

4.3.2 The WHO Guidelines (1999) consider that the evidence in relation to prolonged exposure to environmental noise impacting on long-term stress hormone levels is too inconsistent to draw conclusions.

4.3.3 With regard to cardiovascular effects, the WHO Guidelines conclude that epidemiological studies show that these occur after long-term exposure to noise (aircraft and road traffic) with values of 65 to 70 dBA Leq_{24hour} – however the associations are weak. The association is somewhat stronger for IHD than for hypertension. The WHO identify that although the risks of noise having a negative impact on cardiovascular function are small, they are important because a large number of people are likely to be exposed to such noise levels.

4.3.4 The WHO NNG concludes that more research is needed regarding the association between aircraft noise and cardiovascular end points.

Other Research

Stress Hormones

4.3.5 Various reviews on environmental noise and health have concluded as follows:

- HCN (1999)[2]: the evidence for a causal effect between noise exposure and biochemical effects is limited.
- HC (2002)[3]: the available research does not support the contention that there is a significant risk of chronic stress arising from long term exposure to outdoor daily aircraft noise levels above 65 dBA.
- ECA (2004)[4]: internationally the evidence from epidemiological studies for an impact on long term stress is limited or suggestive only.

All reviews identify the need for further research in this area.

However, some recent studies have identified elevated levels of stress hormones in association with noise exposure at night-time and in children exposed to aircraft noise – see Sections 3.5 and 3.6 below.

4.3.6 The HC and ECA Reviews, and a review by Stansfeld (2000)[7], concluded that the available evidence does not appear to convincingly demonstrate an association between aircraft noise and hypertension or IHD. However, they do conclude that the available studies provide some evidence to suggest that there may be a slight risk of IHD. All reviewers recommend that further research is needed to examine the impact of noise on cardiovascular health. The HCN Review considers that above exposures of 70dBA $L_{eq16\ hour}$ there is sufficient evidence for noise-induced IHD and hypertension.

4.3.7 In 2000 Babisch[41] published a comprehensive review of the literature on environmental noise and cardiovascular disease. Of the 10 studies reviewed by Babisch, 4 showed associations between traffic noise and hypertension. Of these Babisch considered that 2 met requirements in terms of controlling sufficiently for confounding factors. He concluded that there was little epidemiological evidence of an increased risk of hypertension in subjects exposed to traffic noise and some evidence regarding the association between transportation noise and IHD. In 2006 Babisch[42] updated his review to incorporate new studies published since 2000. He concluded that:

- There is no evidence from epidemiological data, that community noise increases (mean) blood pressure in the adult population. However, he notes that this lack of evidence does not discard the hypothesis that there may be a relationship between transportation noise and blood pressure but that the studies undertaken suffer from insufficient power and design difficulties.
- With regard to aircraft noise and hypertension evidence has improved since the previous 2000 review – showing higher risks in higher exposed areas (approximate daytime average noise levels in the range 60 to 70 dBA). The findings for road traffic noise show no consistent pattern.
- For IHD the evidence of association between community noise (review focused mainly on road traffic noise but did include some aircraft noise studies) has increased since the previous review. There is not much indication of a higher IHD risk for subjects who live in areas with daytime average noise levels of less than 60 dBA but across studies for higher noise categories, a higher IHD risk was relatively consistently found – however, statistical significance was rarely achieved.

4.3.8 In an analysis of 43 epidemiological studies (published between 1970 and 1999 for both occupational and environmental exposure) that investigated the relationship between blood pressure and/or IHD disease, van Kempen (2002)[43] concluded that the evidence on noise exposure, blood pressure and IHD is still limited. With respect to hypertension, results were contradictory, a significant association was found for air traffic noise and hypertension but there was little evidence of an increase in blood pressure in subjects exposed to road traffic noise. For IHD, only a few studies were available and the evidence for association between noise exposure and IHD was found to be inconclusive.

4.3.9 Two studies (Babisch, 1999)[44] ‘Caerphilly & Speedwell Studies’) were undertaken to investigate the hypothesis that prolonged exposure to traffic noise at home increases the risk of IHD. The increase in risk in the noise-exposed areas was assessed relative to populations where the noise levels were less than 55 dBA. After the cohorts had been studied over a 10-year period, it was concluded that, solely on the basis of the Caerphilly and Speedwell studies it cannot be deduced that traffic noise increases the risk for IHD.

4.3.10 A Swedish study (Rosenlund, 2001)[45] found that the prevalence of hypertension was higher among people exposed to average noise levels of at least 55 dBA or maximum levels above 72 dBA, around Arlanda airport, Stockholm. However, the methodological approach of this study has been criticised[46].

4.3.11 Goto (2002)[47] reported on a study to investigate the blood pressure levels in those living around an airport in Japan. Examination of study data from 469 women living around the airport, and exposed to varying levels of aircraft noise, found that blood pressure was not associated with aircraft noise level. In a questionnaire survey around Schiphol Airport, Franssen, (2004)[37] found that the risks of poor self-rated health, and of medication use for cardiovascular diseases or increased blood pressure, increased with aircraft noise levels. Franssen concludes that exposure to aircraft noise may be a risk factor for cardiovascular disease.

4.3.12 A study (Willich, 2006[48] , Babisch, 2005[49]) was undertaken in Berlin to determine the association between chronic exposure to road traffic noise and the risk of cardiovascular disease (specifically myocardial infarction). The data were analysed using different approaches by two research groups, both groups conclude that chronic exposure to road traffic noise increases the risk for cardiovascular disease and that the level of risk appears to be related to gender; however, the level of risk determined varies between the two approaches.

4.3.13 The contractility of the stomach was examined in relation to different types of noise (Castle *et al,* 2007)[50]. Subjects were exposed to hospital noise, traffic noise and conversation babble and their gastric myoelectrical activity was recorded. The results indicated that loud noise altered the electrical activity in the stomach particularly in younger people under the age of 50 years.

4.3.14 The link between hypertension and road traffic noise exposure was studied (de Kluizenaar *et al*, 2007)[51]. The study design was cross-sectional (n = 40,856) and participants were inhabitants of Groningen, Netherlands. Before adjustment for confounding variables, road traffic noise exposure was associated with self-reported use of antihypertensive medication in the whole sample, however following adjustment the association persisted in subjects between 45 and 55 years old, and at exposure levels of L_{den} > 55dB. The authors suggested that exposure to high levels of road traffic noise may be associated with hypertension in subjects in this age range, and that the associations are stronger at higher noise levels.

4.3.15 Heart rate, blood pressure and noise perception in relation to aircraft noise was measured in residents around Frankfurt Airport (Aydin and Kaltenbach, 2007)[52]. Two areas were selected, in which aircraft noise was the predominant source of noise created by aircraft taking off but not landing. The responses of residents were measured over a twelve week period, with one area being exposed to air traffic noise for three quarters of the given time, and the other area only exposed for one quarter of the time. Blood pressure and heart rate was monitored in 53 subjects (aged 50-52 ± 15 years) over three months, alongside subjective perception of noise and sleep quality. Thirty one subjects lived to the west of the airport, and were exposed to a nocturnal equivalent continuous air traffic noise level of L_{eq} = 50dBA outside during departures from runway 25. Twenty-two subjects lived east of the airport and were exposed to L_{eq} = 50dBA during departures from runway 07. During opposite flight directions, aircraft noise corresponded to L_{eq} = 40dBA in both areas. The airport operated runway 25 for about 75% of the time, and runway 07 for 25% of the time. Average blood pressure was significantly higher in the West group with higher noise exposure. Morning systolic and diastolic blood pressure was higher in the west group. The East group exhibited a daily parallel between changes in noise and their subjective noise perception, which was not found in the west group. The authors suggested that this was a consequence of higher noise stress levels in the West group, and concluded that a nocturnal aircraft noise level of L_{eq} = 50dBA can have negative effects on subjective noise perception and on objective parameters of circulation.

4.3.16 Perceived noise exposure was also measured in the workplace, and the relationship between cerebrovascular diseases among Japanese male workers (Fujino *et al*, 2007)[53]. A baseline survey was conducted between 1988 and 1990 (n = 110, 792; age range = 40 -79 years) in 45 areas of Japan. Subsequent causes of deaths were established from death certificates. The analysis was performed on subjects who were free from cerebrovascular diseases (age range = 40-59 years) who were in work at the time of the baseline survey. All subjects completed a self-administered questionnaire at the time of the baseline study. The results suggested nose exposure did not increase the risk of cerebrovascular diseases, subarachnoid haemorrhage, or cerebral infarction. However, perceived noise exposure increased the risk of intracerebral haemorrhage diseases. Furthermore, individuals with hypertension were particularly susceptible the effect of perceived noise exposure on the risk of intracerebral haemorrhage, but this association was not seen in subjects without hypertension.

4.3.17 The cardiovascular effects of noise in the workplace were also investigated in two groups of automobile workers (Chang *et al,* 2007)[54]. The high-noise-exposed group (n = 15), (85 ± 8 dBA) had significantly higher systemic vascular resistance than the low-noise-exposed workers (n = 5), (59 ± 4 dBA) during work and sleep periods. The authors suggested that in automobile workers, occupational noise exposure may have sustained, not transient, effects on vascular properties and also enhances the development of hypertension.

4.3.18 The relationship between road traffic and blood pressure and heart rate in preschool children was examined during the night at children's residences, and during the day at Kindergartens (Belojevic *et al,* 2007)[55]. A cross-sectional study was performed on 328 preschool children ages 3-7years, who attended 10 public kindergartens in Belgrade. L_{eq}s were measured during the night in front of the children's homes and during the day in front of the kindergartens. A home was classified as noisy if the L_{eq} exceeded 45dBA during the night and quiet if the L_{eq} was ≤ 45dBA. Noisy and quiet kindergartens were those with daily L_{eq} > 60dBA and ≤ 60dBA respectively. The prevalence of children with hypertensive values of blood pressure was 3.9%, with a higher prevalence in children from noisy residences (5.7%), compared to children from quiet residences (1.48%). Systolic pressure was significantly higher (5mmHg on average) among children from noisy residences, compared to children from both quiet environments. Heart rate was significantly higher (2 beats/min on average) in children from noisy residences. The authors stressed, however, that it was not known if these effects were of a temporary nature and whether they could be reversed upon cessation of the noise exposure.

4.3.19 A cross-sectional study of environmental noise and community health was conducted in neighbourhoods around Sydney Airport, with high exposure to aircraft noise and in a matched control suburb unaffected by aircraft noise (Black *et al,* 2007)[56]. The relationships between health-related quality of life and aircraft noise, and long-term exposure to aircraft noise and adult high blood pressure levels were examined using social surveys. Noise measurements were undertaken that lead to the development of a novel metric – the noise gap index, NGI that includes considerations of background environmental noise. The NGI was developed as an index that is easy to understand by the layperson, and that also quantifies relevant aspects of the potential impacts of aircraft noise. It was found that subjects living in high and medium background environmental noise areas were more likely to be annoyed by the same aircraft noise exposure level than subjects living in low background environmental noise areas. The research concluded that:

- Long-term aircraft noise exposure was significantly associated with chronic noise stress

- Chronic noise stress was significantly associated with prevalence of hypertension

4.3.20 The authors highlight that although there are often instances of increased pharmaceutical drugs for hypertension and stress around airports, no studies have applied cognitive behavioural therapy (CBT) as an intervention to alleviate stress experienced by residents from long-term exposure to aircraft noise living around commercial or military airports, and this may be a valuable tool in helping to decrease the stress-inducing effects of aircraft noise.

4.3.21 Perhaps the most publicised study to examine the effects of aircraft noise on hypertension in recent years is the HYENA study (Hypertension and Exposure to Noise near Airports) (Larup *et al,* 2007)[57]. A total of 4861 people participated in the study, in an age range of 45-70 years old, with a minimum length of residence of five years, living near one of six major European airports (London Heathrow, Berlin Tegel, Amsterdam Schiphol, Stockholm Arlanda, Milan Malpensa and Athens Elephterios Venizelos airport). The selection process created exposure contrast to aircraft noise and road traffic noise within countries, ensuring that sufficient numbers of inhabitants in the appropriate age range had expected exposures > 60dBA and < 50dBA. Participants were interviewed by specially trained staff, and their blood pressure measured on three occasions; at the beginning of the interview, after five minutes' rest, and then again after a further one minute's rest and finally after the interview as a validity control. The mean of the first two readings was used to define blood pressure for the subsequent analyses.

4.3.22 Figure 3 shows the odds ratios for hypertension in relation to aircraft noise during the day ($L_{Aeq,\ 16h}$) and during the night (L_{night}). A rise in odds ratio with increasing exposure is indicated primarily for night-time noise, with no differences found between males and females.

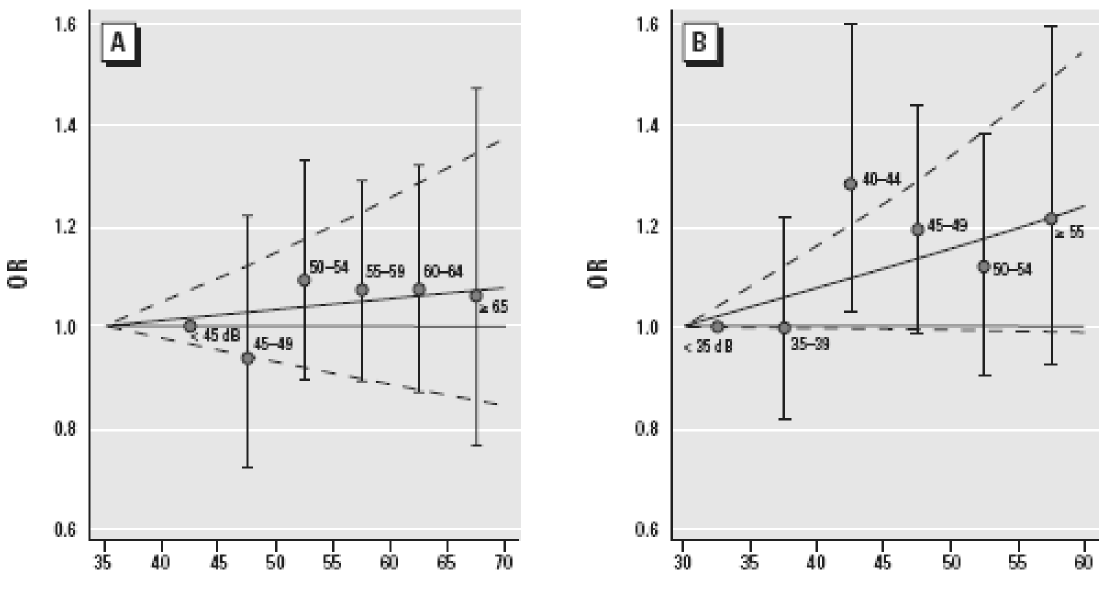

Figure 3: *Odds ratios of hypertension in relation to aircraft noise (5dB categories).* $L_{Aeq,\ 16h}$ *(A) and* L_{night} *(B) were included separately in the model. Adjusted for country, age, sex, BMI, alcohol intake, education, and exercise. Error bars denote 95% confidence intervals for the categorical (5dB) analysis. The unbroken and broken curves show the ORs and corresponding 95% CIs for the continuous analysis. Taken from Jarup et al, 2008.*

4.3.23 Figure 4 shows the odds ratios for hypertension in men and women in relation to average road traffic noise exposure ($L_{Aeq,\ 24h}$) An increase in risk for men with increasing exposure was reported, but this was not found in women

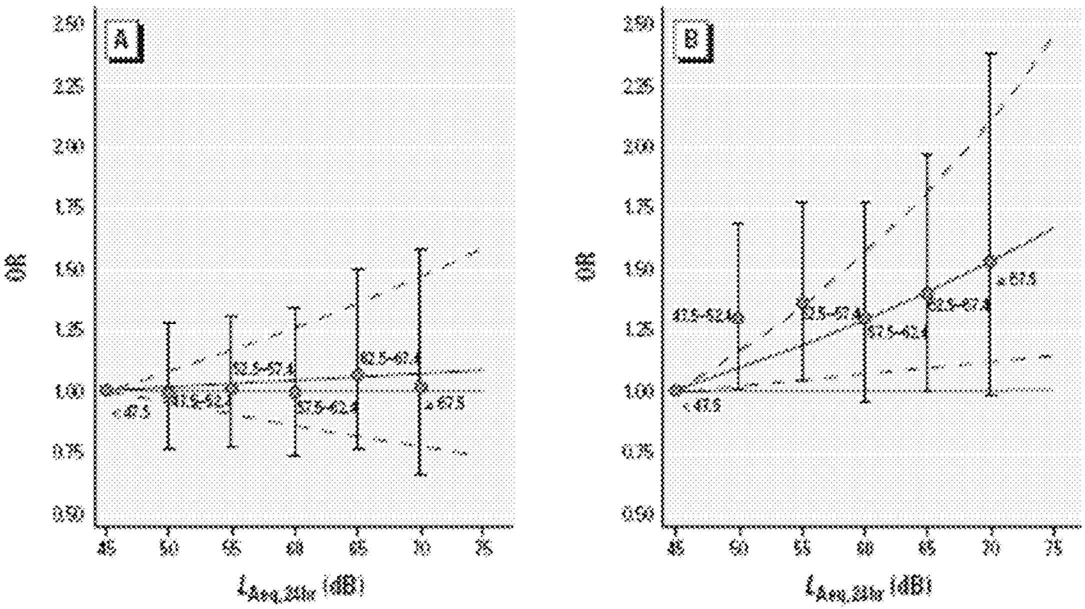

Figure 4: *ORs in women (A) and men (B) in relation to road traffic noise ($L_{Aeq,\ 24h}$, 5 dB categories) separately included in the model. Adjusted for country, age, sex, BMI, alcohol intake, education, and exercise. Error bars denote 95% confidence intervals for the categorical (5dB) analysis. The unbroken and broken curves show the ORs and corresponding 95% CIs for the continuous analysis. Taken from Jarup et al, 2008.*

4.3.24 The results from the HYENA study indicated that there were significant exposure response relationships between exposure to night-time aircraft noise exposure, daily average road traffic noise and risk of hypertension. The authors highlighted that the higher risk for night-time noise may be a consequence of less misclassification of exposure during the night (i.e. participants are more likely to be home during the night). They suggest that the higher night-time risks may also be explained by acute physiological responses induced by night-time noise events that might affect restoration during sleep. The gender difference with relation to road traffic noise was an interesting finding and one that could be explored further. Overall, the conclusions from the HYENA study were that the increased risk of hypertension in relation to aircraft and road traffic noise near airports might contribute to the burden of cardiovascular disease. The authors suggested that that preventative measures should be considered to reduce road traffic noise and night-time noise from aircraft.

4.3.24 As part of the framework of the HYENA study, the acute effects of night-time noise in relation to blood pressure were also reported in 140 subjects (Haralabidis *et al*, 2008)[58]. Measurements of blood pressure were taken every 15 minutes during the study night in participants' homes. Noise level equivalents for every second, every minute and for every 15-minute period in-between blood pressure measurements were calculated. Noise events were classified into four categories:

- Indoor
- Aircraft
- Road traffic
- Other outdoor

4.3.25 The results indicated that both systolic and diastolic blood pressure, as well as heart rate increased with higher noise levels during the preceding minutes, independently of the noise source. Significant increases in blood pressure was also seen when the source of the noise was taken into account. The effects of the source-specific noise were comparable for aircraft, traffic and indoor events and were similar to those of the total measured noise. The authors concluded that the absence of short-term habituation to the cardiovascular effects of noise, especially those during sleep, are likely to support a link between acute and long-term effects of noise exposure and hypertension and cardiovascular disease.

4.3.26 The Defra report examined the effects of environmental noise and the risk of cardiovascular disease, and the main conclusion drawn was that current research suggests an increasing relative risk of myocardial infarction in people living in areas with road traffic sound levels measured outdoors above 65 LAeq 16hr day, increasing up to about 1.4 to 1.5 in areas with road traffic sound levels measured outdoors above 75LAeq 16hr day.

4.3.27 Babisch and van Kamp (2009)[59] evaluated the Exposure-response relationship of the association between aircraft noise and the risk of hypertension. There has been no clear association found between aircraft noise, ischemic heart disease, and myocardial infarction, possibly due to the absence of large scale quantitative studies. There is sufficient qualitative evidence, however, that aircraft noise increases the risk of hypertension in adults. The authors evaluated the literature for the WHO working group on “Aircraft Noise and Health”. With respect to the needs of a quantitative risk assessment for burden of disease calculations, the authors attempted to derive an exposure-response relationship based on a meta-analysis. An in-depth discussion of the criteria for inclusion is given in the paper, with five studies being chosen as the basis for analysis. An approximate graphical representation of the results are given in Figure 5, but authors caution that no conclusions regarding possible threshold value or noise level related risks (in absolute terms) can be drawn.

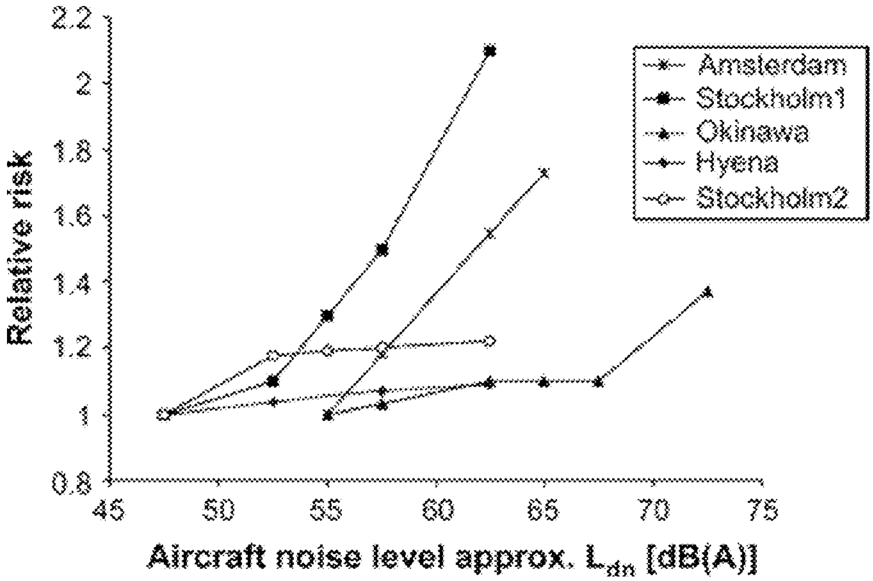

Figure 5: Association between aircraft noise level and the prevalence or incidence of hypertension

4.3.28 When linear trend coefficients of all the five studies are calculated and pooled afterwards (‘regression approach’) the pooled effect estimate of the relative risk is 1.13 (95% CI = 1.00-1.28) per 10 dBA. The authors caution that the limitations involving the pooling of studies due to methodological differences in the assessment of exposure and outcome between studies mean that the association must be viewed as preliminary. It is suggested to use Lden ≤ 50 or Lden ≤ 55 dBA as a reference category of the exposure-response relationship. The respective relative risks for subjects who live in areas where Lden is between 55 to 60 dBA and between 60 to 65 dBA would then approximate to 1.13 and 1.20, or 1.06 and 1.13, respectively.

4.4 Performance

Background and WHO Guidelines

4.4.1 The WHO Guidelines report that studies of both laboratory subjects and workers exposed to occupational noise, have found that noise adversely affects cognitive task performance. Such studies have shown that although noise induced arousal may produce better performance in simple tasks in the short term, cognitive performance substantially deteriorates for more complex tasks. Reading, attention, problem solving and memorisation are among the cognitive effects most strongly affected by noise.

4.4.2 There have been a number of field studies of school children, which have observed that noise impairs their cognitive performance (see Section 3.6). However, according to the WHO Guidelines there is no published research on whether environmental noise at home impairs cognitive performance in adults.

Other Research

4.4.3 In agreement with the WHO Guidelines, other reviews report that there is good evidence from laboratory studies that noise exposure impairs performance in adults. The literature search and reviews considered have not identified any new research published since the WHO Guidelines, which contributes significantly to the understanding of the impact of aircraft noise on the performance in adults. However, reference has been found[7] to a paper published in 1986, which compared the self-reports of everyday errors (failures of attention, memory and action) by subjects living in an area of West London exposed to a high level of aircraft noise with those in a similar group who lived in an area with low level of aircraft noise. The high-aircraft noise group reported a higher frequency of everyday errors and so did noise-sensitive subjects. According to Stansfeld (2000)[7], concern has been expressed that there may be some confounding by neuroticism in these findings, and studies of the effects of noise on cognitive tasks do suggest that neuroticism and anxiety are important in determining individual differences in response to noise.

4.4.4 The HCN Review concludes that the evidence for causal relationship between environmental noise and decreased general performance is limited.

4.4.5 Brain response known as event-related potentials (ERPs), were measured in environmental noise-exposed workers compared to a control group (Chiovenda *et al*, 2007)[60]. The P300 response, associated with selective attention and behavioural response was measured in both groups in response to an environmental stressor (background traffic noise) versus a non-specific stress inductor (Stroop test). Comparison between a groups of noise exposed workers (traffic police officers), and a control group (office employees) did not show marked differences in cognitive and emotional profiles. The amplitude of the baseline cognitive P300 potential, recorded during a discrimination task, was higher in noise-exposed workers than in controls, and this enhancement was associated with a lower level of trait anxiety along with better mood profiles. There was also a wider P300 amplitude reduction in traffic police officers than in controls, under noisy conditions due to traffic. The effect of the Stroop test as a stress inducer was negligible and similar in the two groups. The authors suggested that the wider amplitude of the P300 response in traffic police officers in the baseline condition could be a sign of cross-modal cerebral plasticity, which would enhance the attentive processes in the 'stress-free' sensory channel. In addition, the noise-exposed workers presented a higher cerebral sensitivity to stress when they were exposed to the habitual environmental stressor.

4.4.6 The after-effects of noise-induced sleep disturbance on executive functions were investigated with motivational traits as mediating variables (Schapkin *et al,* 2007)[61]. Thirty-two subjects performed a visual Go/Nogo task with simultaneous EEG recording after a quiet night and after three nights with railway noise at different noise levels (L_{eq} = 40, 44 and 50; L_{Amax} = 50-62, 56-68 and 62-74dBA respectively). Motivational traits were "hope of success" (HS) and "fear of failure" were assessed. Subjective sleep rating worsened with increased noise level, but noise-induced sleep disturbance did not affect performance immediately following sleep. However, in the ERP, an attenuation of the N2 and P3 amplitude as well as an increase in N2 latency in Noisy conditions was found. Only subjects who scored low in HS showed a reduction of the N2 after Noise, while subjects who scored high in HS did not. The N2 and P3 were larger in high HS than in low HS subjects in Nogo trials only. Similarly, low FF subjects had larger N2 and P3 than high FF subjects in Nogo trials only. The authors suggested that achievement motivation modulates executive control in the brain and stimulus-response mapping processes as well as their resistance against after-effects of noise-induced sleep disturbance.

4.4.7 The prediction of work efficiency in early adolescence under the effects of noise was investigated (Fosnaric and Planinsec, 2008)[62]. Of all three stress factors measured (climate, noise, light) in terms of the work performance of early adolescents, only noise was a significant contributor.

4.5 Night-time Effects

Background and WHO Guidelines

4.5.1 It is acknowledged that uninterrupted sleep is a prerequisite for good physiological and mental well being. The WHO Guidelines conclude that sleep disturbance is a major effect of environmental noise and that exposure to environmental noise may cause primary effects during sleep (e.g. awakening), and secondary effects that can be assessed after night-time noise exposure (e.g. next day tiredness). WHO identify the elderly, newborn, shift workers and persons with physical or mental disorders as being particularly vulnerable to sleep disturbance.

4.5.2 A report (Porter, 2000)[63] prepared for the UK Department of Transport by National Air Traffic Services Ltd, considered the potentially adverse effects of night-time aircraft noise on people and reviewed available evidence. Porter's review is summarised below and provides the basis for the summary of the scientific literature presented here; it is supplemented by findings published since 2000 and the conclusions of various other reviews.

Porter categorised the potential effects of night-time aircraft noise as:

- ***Acute Responses:*** immediate or direct disturbances such as sleep disturbance (e.g. awakenings, sleep stage changes), other physiological changes that coincide with the noise events (e.g. increase in heart rate or blood pressure, or immune system effects) or acute annoyance.
- ***Total Night Effects***: aggregations of acute responses over a total night, such as sleep loss or frequent disturbances breaking up the general sleep pattern.
- ***Next Day Effects:*** short term effects of the acute responses and total night effects (e.g. next day tiredness, degradation of task performance, short-term annoyance).
- ***Chronic Effects***: pervasive long-term consequences of continuing acute responses and next day effects. These are the same potential effects as discussed above in general terms (e.g. annoyance, cardiovascular and physiological effects, and mental health effects.)

4.5.3 Above a certain threshold noise can cause awakening, and at levels significantly lower, it can also induce sleep stage changes. A major UK field study (Ollerhead, 1992)[64] indicated that aircraft noise even at high levels has a relatively small effect on awakening from within sleep during the night. Ollerhead concluded that below outdoor event levels of 90 dBA SEL (80 dBA Lmax) aircraft noise events are most unlikely to cause any measurable increase in the overall rates of sleep disturbance experienced during normal sleep. He also concluded that for outdoor event levels in the range 90-100 dBA SEL (80-95 dBA Lmax) the chance of the average person being awakened is about 1 in 75. Porter reports that Ollerhead's findings appear to have been corroborated by subsequent studies in the USA.

4.5.4 Airport neighbours often cite sleep disturbance at the beginning and end of the night as the most objectionable and annoying aspect of night-time aircraft noise. Reduction in sleep duration may be caused if there is a delay in the onset of sleep or premature awakening. Experimentally it is difficult to ascertain whether or not specific awakenings are caused by aircraft noise events or just happen to coincide. Additional analyses of the 1992 UK field study data were not able to conclude whether aircraft noise significantly delayed sleep onset, or had a significant effect on premature awakenings.

4.5.6 In themselves, the acute physiological responses to noise during sleep may not be harmful; but as discussed more generally in Section 3.3 there is concern they may lead to permanent health impacts (e.g. hypertension).

4.5.7 A review by Carter, (1996)[65] indicated that slow wave sleep (SWS) in young adults may be reduced by intermittent noise, such as that from aircraft. SWS is often considered to be the most restorative component of sleep, so any SWS sleep loss during the normal sleeping period might be particularly detrimental. It has also been speculated that reduction in SWS may impact on the immune system.

4.5.8 Generally, studies of experimentally enforced disturbance of sleep have shown that sleep deprivation can result in next day performance and functioning decrements. Sleep deprivation studies have indicated that repeated arousals during sleep, even if brief, systematically reduce daytime alertness by an amount which depends on the frequency of arousals and the age of the subjects. To-date, there appears to be no evidence that sleep losses comparable to those experienced in sleep deprivation studies are likely to be caused by aircraft noise, even at night-time aircraft traffic levels currently experienced at busy airports. Nevertheless, the possibility of noise induced sleep loss cannot be ruled out in the case of especially sensitive people.

4.5.9 Whether or not it has actually happened, individuals may perceive that aircraft noise has disturbed their sleep and caused effects such as tiredness, bad mood and lack of concentration. There is evidence that such perceptions are prevalent, and it is possible that they may in turn induce annoyance and worry about health effects.

4.5.10 Sleep is a state of reduced activity that might be cardio-protective – it has therefore been hypothesised that chronic reduction of the respite by noise could have implications for long-term cardiovascular health.

4.5.11 Porter concludes:

- The research evidence suggests a disparity between subjective perceptions of noise induced sleep disturbance (and consequent annoyance) and objectively measured disturbance. Subjective reactions are strong, whereas noise has a relatively small effect on the incidence of physiological disturbance. High levels of aircraft noise can waken people but at current levels of exposure near airports, aircraft noise is one of very many causes of sleep disturbance.

- It is evident that night-time environmental noise adversely affects health by causing chronic subjective reactions which affect quality of life. As yet, there appears to be no hard scientific evidence of chronic objective effects (i.e. clinically significant health impairment) but the possible existence of such effects cannot be rejected.

HCN Review

4.5.12 In the HCN Review, it is concluded that there is sufficient evidence that exposure to noise can induce sleep disturbance in terms of changes in sleep patterns, in sleep stages, in subjective sleep quality and awakenings. In addition noise exposure during sleep causes other effects such as an increase in heart rate and after effects such as decreased mood the next day. However, the HCN report considers evidence for other effects is limited (hormone levels and performance the next day) or inadequate (immune system).

More Recent Studies

4.5.13 Since the publication of the reviews of Porter and the HCN, the results of further field studies of the effects of aircraft noise on sleep have been reported. A number of papers looking specifically at the impact of night-time noise on stress hormone levels, performance and subjective perceptions of aircraft noise at night have also been published. Some of the key findings from the work published more recently are presented below.

Stress Hormone Levels

4.5.14 The published research findings on the impact of night-time environmental noise exposure on stress hormone levels are inconsistent. Maaß (2004)[66] reports findings of a sleep laboratory study and associated field study investigating the effects of nocturnal aircraft noise; he found no significant influence of aircraft noise on excretions of stress hormones or electrolytes.

4.5.15 Maschke (2004)[67] has observed that average stress hormone levels may be acutely raised by traffic noise at night. At the same time, the quality of the sleep experienced by the test persons and their feeling of well-being next morning is poorer. Exposure to 16 overhead flights with maximum levels of 55 dBA produced a significant increase in the secretion of stress hormones. He also notes that the general findings in relation to noise exposure at night and stress hormone levels in overnight urine samples are inconclusive, and show individuals with increases in stress hormone levels and others with decreased values.

4.5.16 In a study by Babisch (2001)[68] of middle aged women living in Berlin, whose bedrooms or living rooms faced streets of varying traffic volume, significant associations were found between noise exposure and the nocturnal secretion of stress hormones in urine, with regard to exposure in the bedroom (but not in the living room). This indicated a higher chronic physiological stress response in noise exposed subjects as compared to the less exposed. Babisch concludes that, the fact that noise effects were only seen with regard to exposure of the bedroom and not the living room of the subjects, suggests that particularly night-time disturbances of sleep may be associated with adverse effects of traffic noise.

4.5.17 Based on a review of recent studies on the relationship between traffic noise disturbance at night and increases in stress hormones Ising (2004)[69] concludes that:

"…noise exposures over time periods of years may induce, in a certain percentage of exposed persons, permanent changes of stress hormone regulation, along with possible consequences in terms of functional and organic damages."

4.5.18 Diamond et al (2000)[70] undertook a study (by interview and questionnaires) of the perceptions of aircraft noise, sleep and health around major UK airports. They found that:

- Sleep disturbance attributed to aircraft noise was associated with greater health problems.
- Where night noise is relatively high, it causes annoyance to local residents and at two of the airports studied annoyance due to night noise exceeds that due to day time noise.
- Where noise is relatively high, between 10% and 20% of respondents reported having difficulty getting to sleep at night and being woken up in the morning.
- Very few people reported that their health was "extremely affected" by aircraft noise at night. However, between 30% and 60% of respondents at the various sites perceived their health to be "somewhat affected".
- Respondents who reported long term or recent physical or mental problems, or stress in their job or in their life generally, were more likely to report their health was affected by aircraft noise at night.

4.5.19 Öhrström (2001, 2004)[71,72] undertook a study (by questionnaire) to determine the health effects before and one year after a substantial reduction in road traffic. Based on the study, it was concluded that exposure to high levels of road traffic noise significantly affects perceived sleep quality (and also annoyance and psycho-physiological health and well-being).

Performance

4.5.20 Schapkin[73,74] reports that the scientific literature on whether noise-induced sleep disturbance affects the next day performance of adults is mixed. He notes that the scientific literature suggest that disturbed sleep affects performance in complex tasks, but that performance in simple psychomotor tasks can probably be prevented by individuals exerting additional effort. Schapkin investigated the impairment of neuronal mechanisms underlying performance after sleep disturbance by measuring event-related brain potentials (ERPs) – this is a new approach to investigating the impact of night-time noise. His results suggested that physiological costs to maintain performance are increased after noisy nights and that ERPs may be more sensitive indicators of moderate sleep disturbances caused by noise than performance measures.

Other Recent Field Studies

4.5.21 Of particular interest from recent studies of the effects of aircraft noise on sleep around Cologne-Bonn and Schiphol airports are the findings on the noise level at which there is an onset of effects:

- Passchier-Vermeer (2002)[75] undertook a large wide ranging field study on the effects of night-time noise in the vicinity of Schiphol airport during 1999 and 2001. She concluded that that the threshold of aircraft noise induced probability of motility is on average 32 dBA Lmax (indoor). The effect increases with increasing noise level, at 68 dBA Lmax (indoor) the probability of motility during an aircraft noise event was on average about 3 times the probability of motility in the absence of aircraft noise.
- Basner (2006)[76] reports on a field study (using electroencephalography - EEG) to investigate the influence of night-time aircraft noise on sleep, carried out around Cologne-Bonn airport in 2001 and 2002. He developed a dose-response relationship between maximum indoor noise levels (dBA Lmax) and probability of sleep stage change to awake or stage 1. He found that the onset of awakening due to aircraft noise increased at noise levels above around 33 dBA Lmax. The awakening probability just above this threshold is very low, for example 2 out of every 1000 people exposed to an ANE of 34 dBA Lmax will show a noise-induced awakening but at noise levels of 70 dBA Lmax the probability of sleep stage change to awake or stage 1 is of the order of 88 people in every 1000 (about a 1 in 11 chance of a sleep stage change to awake or stage 1).

4.5.22 It is not possible to consider the findings presented in paragraphs above by way of a simple comparison, as they do not measure sleep disturbance in the same way (also note that Ollerhead's results relate to outdoor noise levels and Passhier-Vermeer and Basner's findings to indoor noise levels). For example, Passchier-Vermeer reports probability of motility, Basner reports on sleep stage changes to awake or stage 1 and Ollerhead used a method based on filtering motility data. Nonetheless, a very crude consideration of the data presented above indicates that there are discrepancies in the findings of noise levels at which the onset of sleep disturbance occurs.

4.5.23 Passchier-Vermeer (2003)[77] has carried out an analysis of data from seven studies (including those of Ollerhead, Fidell and Passchier-Vermeer identified above) into behavioural awakening as a result of exposure to commercial aircraft noise exposure to populations. She developed a method to convert onset of motility or EEG awakening to behavioural awakening. Her analysis concludes that the onset of behavioural awakening due to exposure to aircraft noise is 54 dBA SEL (indoor).

4.5.24 Subsequent to Porter's review, Fidell (2000)[78] summarised the findings of studies to investigate the effects on sleep disturbance of changes in aircraft noise near three airports in the USA (the findings around two of the airports were included in Porter's review the third airport was not). At each of the airports there was a change in night-time aircraft noise exposure during the study period (e.g. due to closure of a runway). Fidell found no major differences in noise-induced sleep disturbance as a function of changes in night-time aircraft noise exposure. He concluded that the results indicate that relatively few night-time noise intrusions disturb sleep, and that residential populations near airports seem well-adapted to night-time noise.

4.5.25 Michaud (2007)[79] undertook a review of field studies of aircraft noise induced sleep disturbance. The review focuses on field studies between 1990 and 2003 and takes into account the work of Ollerhead, Fidell and the study of sleep disturbance conducted in the vicinity of Schiphol Airport by Passchier-Vermeer (2002). Michaud summarises his review as follows:

> *" The literature review of recent field studies of aircraft noise-induced sleep disturbance finds that reliable generalisation of findings to population-level effects is complicated by individual differences among subjects, methodological and analytic differences among studies, and predictive relationships that account for only a small fraction of the variance in the relationship between noise exposure and sleep disturbance. It is nonetheless apparent in the studied circumstances of residential exposure that sleep disturbance effects of night-time aircraft noise intrusions are not dramatic on a per-event basis, and that linkages between outdoor aircraft noise exposure and sleep disturbance are tenuous. It is also apparent that aircraft noise-induced sleep disturbance occurs more often during the later part of the night; that indoor sound levels are more loosely associated with sleep disturbance than outdoor measures; and that spontaneous awakenings, or awakenings attributable to non-aircraft indoor noises, occur more often than awakenings attributed to aircraft noise."*

4.5.26 In the recent review on environmental noise, sleep and health Muzet (2007)[80] explains the auditory and non-auditory effects of noise (Figure 6). Sleep disturbance is a non-auditory effect of noise. The input to the auditory area of the brain though the auditory pathways is prolonged by inputs reaching both the brain cortical area and the descending pathways of the autonomic functions. Therefore the sleeping body still responds to stimuli from the environment, although the noise sensitivity of the sleeper depends on several factors. These can be noise dependent e.g. type of noise, intensity, frequency, nose spectrum, interval, signification and the difference between the background noise level and the maximum amplitude of the occurring stimulus. Other factors are related to the sleeper, e.g. age, sex, personality and self-estimated sensitivity to noise.

4.5.27 The immediate effects of noise are seen as sleep disturbance, quantified by number and duration of nocturnal awakenings, number of sleep stage changes, and modifications in their amount. Also changes in the autonomic functions such as heart rate, blood pressure, vasoconstriction, and respiratory rate are observed.

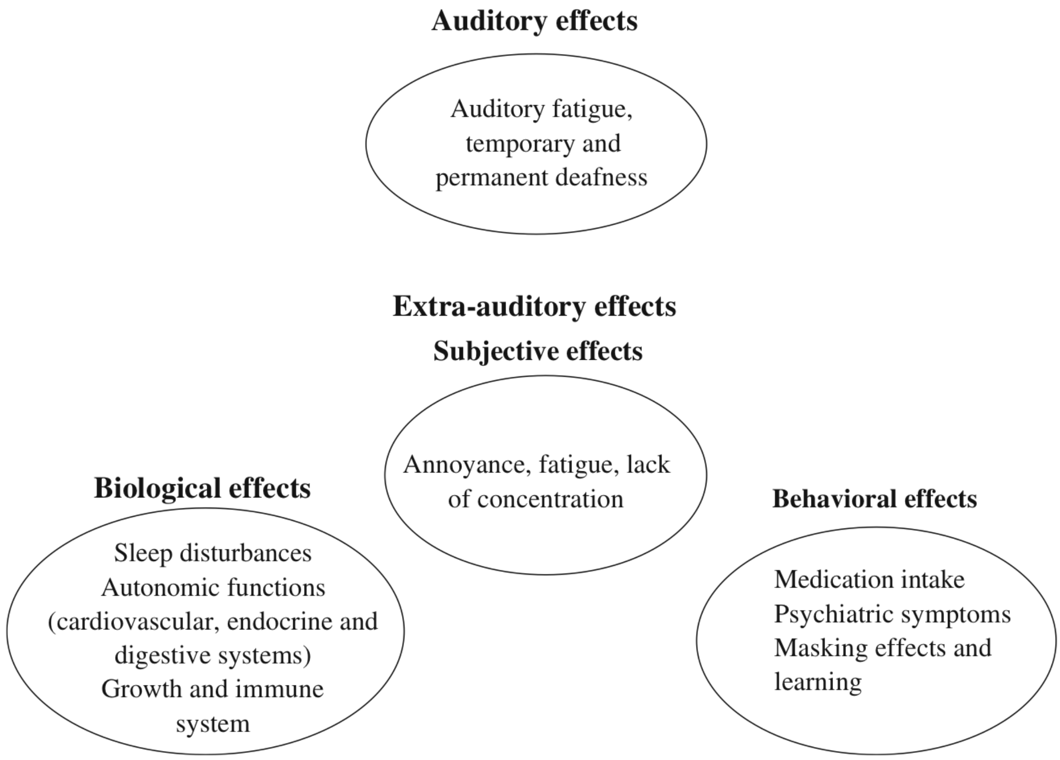

Figure 6: *Auditory and non-auditory effects of noise, taken from Muzet (2007)*

4.5.28 Longer sleep latency and premature final awakening can reduce TST. Reports suggest that intermittent noises with peak noise levels of 45dBA and above can increase the time to fall asleep to 20 minutes. Combined with this, sleep pressure is reduced after the first 5 hours, therefore in the morning noise events are more likely to prevent the sleeper from going back to sleep.

4.5.29 Awakenings have a much higher threshold in deep sleep, e.g. SWS or REM, and a much lower threshold in lighter stages of sleep. The threshold depends on physical characteristics of the noisy environment (intermittent or sharp rising noise occurring above a low background noise will be particularly disturbing), as well as noise signification.

Sleep stage modifications

4.5.30 Nocturnal awakenings can be observed for 55dBA and above, and disturbance of normal sleep can be observed for peak noise levels between 45 and 55dBA. To protect noise-sensitive people, the WHO recommended a maximal level of 45dB inside the bedroom, whereas for the same period the mean recommended level (integrated noise level over the 8 nocturnal hours: Lnight) was 30dB. SWS is the most restorative sleep stage, whereas REM is important for memory consolidation. Carter (1996) reported that SWS might be reduced in young sleepers subjected to intermittent noise. Also, Muzet has previously reported that REM sleep rhythmicity could also be affected by environmental noise exposure. It is common to see a reduction in SWS and REM and an increase in shallower sleep stages, which can become chronic and detrimental. Long-term studies of such reduced SWS are worth exploring and may prove to be important.

Autonomic responses

4.5.31 Heart rate changes and vasoconstrictions can be seen at much lower noise levels than are found to induce sleep disturbance and indicate that such disturbance can be felt when asleep even if there is no conscious memory of it the next day. The health effects of such responses can be cumulative, over a few thousand stimuli per night.

Secondary effects

4.5.32 Secondary effects include the subjective evaluation of sleep disturbance due to noise, such as complaints about sleep quality, delayed sleep onset, nocturnal awakenings, and early morning waking. They are often accompanied with increased sleepiness, tiredness and need for compensatory resting periods the following day.

4.5.33 Findings show that the subjective assessment of sleep quality does not accurately correspond to the objective measurement of sleep. When the number of noise events increase, the number of sleep modifications and/or awakenings also increases, but not proportionately. Porter (2000) found that noise heard at night was more intrusive and noticeable than noise heard during the day. This is due to reduced outside and inside background noise at night, and the circadian phase. It may also be a time of increased sensitivity to noise. Therefore it is wise to be cautionary when relying entirely on subjective reports of noise-related sleep disturbance due to their questionable validity.

4.5.34 Muzet (2007) reports that sleep disturbance occurring during the early part of the night and early morning prior to the natural time of awakening seem to be the most intrusive. This results in daytime sleepiness, fatigue and lower work capacity and increased accident rate. Fear of living under the flight path can also complicate the issue of accurately assessing subjective sleep quality as a result of noise, making the clarity of the relationship difficult to ascertain.

Other secondary effects

4.5.35 Stress hormones such as cortisol, noradrenaline and adrenaline are increased the following morning and there are also reports of cognitive impairment the next day.Physiological sensitivity to noise can depend on the age of the sleeper. EEG changes and awakening thresholds are on average 10dBA higher in children than in adults, however their cardiovascular sensitivity to noise is similar to older people.

4.5.36 In summary, there are conflicting findings, partly down to the difficulty in ascertaining a clear dose-effect relationship between noise and sleep disturbance, and the degree of interaction of confounding variables. The factors include noise characteristics, noise sensitivity, and the context of the environment.

4.5.37 Muzet (2007) suggests that future research should focus on the long term effects of night-time noise exposure of different populations. A study of specific sub groups thought to be at risk, i.e. children, elderly, self-estimated sensitive people, insomniacs, sleep disorder patients, night and shift workers would be useful to assess differences between populations. Finally, the combined effects of noise exposure and other physical agents or stressors during sleep should be investigated to provide further understanding of the pathways in which noise disturbance effect sleep.

4.5.38 The Defra report 2009 concluded that no single dose-response relationshop could be recommended for sleep disturbance as part of a valuation methodology. It is suggested that investigation into the linkage between the transient effects of noise on sleep and potential long-term chronic health effects is required.

4.5.39 The HPA report discusses the difficulty in obtaining a dose-response relationship between environmental noise and sleep disturbance due to the differences in results between laboratory and field studies, and also the issue of habituation to noise.

4.5.40 A literature review on aircraft noise and sleep disturbance (Jones 2009)[81] which explores this area in more depth was produced by the ERCD, and is available for download from the CAA website.

4.6 Noise and Children

Background and WHO Guidelines

4.6.1 Children are generally considered to be a vulnerable group, that may be less able to cope with the impacts of noise exposure and they may be at greater risk of harmful effects. In a review of the non-auditory effects of noise on health, Stansfeld (2003)[5] explains that:

> *"It is likely that children represent a group which is particularly vulnerable to the non-auditory effects of noise. They have less cognitive capacity to understand and anticipate stressors and lack well-developed coping strategies. Moreover, in view of the fact that children are still developing both physically and cognitively, there is a possible risk that exposure to an environmental stressor such as noise may have irreversible negative consequences for this group."*

4.6.2 Stansfeld (2000)[7] also notes that some children in the population may be more vulnerable to noise effects than others. He concludes that there is limited evidence that children who have lower aptitude or other difficulties, such as learning difficulties and cerebral palsy, may be more vulnerable to harmful effects of noise on cognitive performance.

4.6.3 The WHO Guidelines provide a brief overview of the effects of environmental noise on children. They conclude that chronic exposure to aircraft noise during early childhood appears to impair reading acquisition and reduces motivational capabilities (this is based on the studies of Los Angeles and Munich Airports – see below). It is also noted that of recent concern are the concomitant psychophysiological changes (blood pressure and stress hormone levels). The WHO Guidelines consider that the evidence on noise pollution and health is strong enough to warrant monitoring programmes at schools, and that schools should not be located near major noise sources, such as airports.

Other Research

4.6.4 During and since the late 1990s there has been a significant amount of research published investigating the effects of aircraft noise on children (particularly focusing on cognitive effects). Substantial studies have been undertaken around European airports:

- The Munich Airport Study (Hygge, 1998)[82] took advantage of a natural experiment created by the closing of an existing airport and the opening of a new airport. Before the change over of airports, children at both sites were recruited into experimental and control groups. One set of data were collected prior to the change over of the airports, the second set a year later and a third set two years later. The children were assessed on physiological, perceptual, cognitive, motivational and quality of life measures.
- The West London Schools Study (WLSS – Stansfeld, 2000)[83] a cross-sectional study which was carried out in schools in the area surrounding Heathrow Airport, to determine the association of aircraft noise exposure with cognitive performance. A total of 236 children from 20 schools took part in the study, 10 high noise schools and 10 control low noise schools.
- The Schools Environment and Health Study (SEH) – Haines (2001)[84] - a study around Heathrow airport to compare the school performance and health of children attending four schools in a high aircraft noise area, with those of children from four matched control schools in a low aircraft noise area.
- The RANCH study (Road Traffic and Aircraft Noise Exposure and Children's Cognition and Health; Effect Relationships and Combined Effects) – Stansfeld (2005)[85] – a cross-sectional study that enrolled a total of 2,844 children from 89 schools around Schiphol (Netherlands), Heathrow and Barajas (Spain) Airports. This Study is the largest known epidemiological study undertaken of exposure and children's cognition and health.

4.6.5 A body of research available from a study undertaken around Los Angeles Airport by Cohen[86,87] published in the early 1980s is also widely cited in the scientific literature. In the Los Angeles Study children in four schools exposed to high levels of noise were matched with children in three low noise schools, a first wave of measurements were followed up a year later.

4.6.6 The findings of these key studies are summarised below, along with pertinent findings from other recently published studies.

Cognition

4.6.7 Across the literature the evidence for the effects of noise exposure on child health is strongest for cognitive effects; however the effects of noise have not been found uniformly across all cognitive functions. Stansfeld (2003)[5] summarises (this summary includes amongst others the findings of the Munich, Heathrow and Los Angeles studies described above) the effects that have been found for children exposed to high levels of environmental noise as:

- Deficits in sustained attention and visual attention.
- Difficulties in concentrating (based on teachers' reports).
- Poorer auditory discrimination and speech perception.
- Poorer memory requiring high processing demands.
- Poorer reading ability and school performance on national standardised tests.

4.6.8 More recent substantive findings on cognitive performance come from the RANCH Study. This study found that exposure to chronic aircraft noise could impair cognitive development in children, specifically reading comprehension. The results indicated a linear exposure-effect association between exposure to aircraft noise and impaired reading comprehension and recognition memory in children. The study found that aircraft noise exposure was not associated with recall, impairment in working memory, prospective memory or sustained attention. For road traffic noise the study found no association with reading comprehension, recognition, working memory, prospective memory or sustained attention and that exposure to road traffic noise improved recall; the RANCH team could find no definitive explanation for this latter finding. Stansfeld suggests that aircraft noise, because of its intensity, the location of the source and its variability and unpredictability is likely to have a greater effect on children's reading than road traffic noise, which might be of a more constant intensity.

4.6.9 Shield (2003)[88] compared external noise levels at over 50 London schools (schools were not in areas exposed predominantly to aircraft noise) with the schools' scores in standardised assessment tests (SATs) of children aged 7 to 11. She found significant relationships between external noise levels and SATs scores, with environmental noise having a detrimental effect upon children's performance; the relationship being stronger for older children. A similar study was carried out at schools located around Heathrow airport, in this study no obvious strong consistent relationship was found between noise and SATs scores, although the results suggest that aircraft noise may have a negative effect upon SATs scores for reading.

4.6.10 The HCN Review considers the findings of the Munich, WLSS and Los Angeles studies and concludes that there is sufficient evidence for a causal relationship between aircraft noise and the performance of children in schools.

General Reviews

4.6.11 Matheson (2003)[89] undertook a review of the Los Angeles, Munich and WLSS aircraft noise studies and summarised the findings in relation to stress response, health outcome measures and children's cognition and performance as shown in Table 1. The findings on aircraft noise from the more recent RANCH Study have also been added to Table 1.

Table 1: Summary of the Findings for the Los Angeles Study, Munich Study, West London Schools Study and RANCH Study

(From Matheson, 2003[75] with RANCH results added)

Measure	Los Angeles	Munich	WLSS	RANCH
Annoyance/Quality of Life	—	✓	✓	✓
Motivation and Helplessness	✓	✓	—	—
Stress Hormones	—	✓	**X**	—
Blood Pressure	✓	✓	—	**?**
Reading	**X**	✓	✓	✓
Long-term Memory	—	✓	**X**	**X**
Working Memory	—	✓	**X**	**X**
Attention	✓	✓	**X**	**X**

Key: ✓ = significant effect observed **X** =no significant effect observed — = no test run ?= mixed findings (see below)

4.6.12 The conclusions drawn by Matheson for the Los Angeles, Munich and WLSS studies and more recent findings on aircraft noise from the RANCH Study are as follows:

- The results from the Munich and WLSS indicate quite clearly that chronically noise-exposed children experience increased levels of annoyance and diminished quality of life. The RANCH Study supported these conclusions on annoyance and found that increasing exposure to aircraft noise was associated with increasing annoyance responses in children.
- Taken together, the results of the Los Angeles and Munich studies consistently suggest that living in a noisy environment does impair motivation in children.
- The issue of whether chronically noise exposed children have raised levels of stress as indicated by neuroendocrine indicators of stress is still unresolved. (Note: the Munich study found that overnight resting levels of both adrenaline and noradrenaline were significantly higher in those exposed to aircraft noise but observed no relationship between cortisol levels and noise exposure. However, the WLSS found no significant differences in adrenaline, noradrenaline or cortisol levels in those exposed to noise compared with a control group.)
- The findings from both the Los Angeles and Munich studies provide evidence for chronic noise exposure being associated with increased physiological stress as indicated by raised blood pressure. In a subset of the RANCH Study utilising data from around Heathrow and Schiphol only (Kempen, 2006)[90] the relationship between aircraft noise and blood pressure was not consistent; in the Dutch sample, blood pressure increased statistically significantly as aircraft noise exposure increased but this was not the case with the British sample. Kempen concludes that the findings of the RANCH Study taken together with previous studies, suggest that no univocal conclusions about the association between aircraft noise exposure and blood pressure can be drawn.
- The results from Munich and WLSS point to the conclusion that chronic exposure to aircraft noise impairs children's performance on difficult, and only difficult, reading test items. The RANCH Study found a linear exposure-effect association between exposure to aircraft noise and impaired reading comprehension. In the Los Angeles study no effect was found for reading performance – it is considered that these results are anomalous and attributable to poor study design.
- In terms of noise impact on long-term memory and working memory the findings of the Munich and WLSS studies do not carry a clear message as to whether noise exposure has an effect. The RANCH Study found that exposure to aircraft noise was not associated with impairment in working or prospective memory but that there was an association with recognition memory. (Note – the data on the WLSS above relates to noise exposures at school). When the WLSS cognitive performance data was analysed (Matsui, 2004)[91] in terms of home noise exposure for the children attending the 10 high noise schools, a significant exposure-response relationship was found between aircraft noise exposure at home and performance on memory tests but there was no strong association with reading comprehension or sustained attention.)

4.6.13 The Los Angeles and Munich studies provide some evidence for an effect of chronic aircraft noise exposure on attention but this was not replicated in the WLSS or RANCH Study.

4.6.14 The ECA Review finds that there is sufficient evidence supporting a conclusion that chronic noise exposure at schools affects child health and performance. It also considers that there is a need for further data to drive dose-response curves for guidelines on the noise threshold level before effects manifest.

4.6.15 The HC Review focuses on studies of the impact of aircraft noise in Munich, Los Angeles and Sydney. As discussed above both the Munich and Los Angeles studies found evidence for a link between aircraft noise and blood pressure; however, the Health Canada reviewers suggest that the results of these studies are weakened by inconsistency of results (Los Angeles) and poor characterisation of the noise exposure and lack of control of some potentially confounding factors (Munich). The Sydney study showed no effect of aircraft noise on blood pressure.

4.6.16 The HC Review also considers the evidence from the Munich Study, that aircraft noise exposure results in increased catecholamine secretion, but again has reservations in terms of the findings in relation to interpretation of noise exposures and consideration of confounding factors. Overall the HC Review concludes that the Munich airport study has provided strongest evidence for an association between aircraft noise and stress related physiological effects in children, but that there are too few studies to provide conclusive evidence of a cause and effect relationship between aircraft noise and physiological effects.

4.6.17 Babisch (2006)[92] undertook a review of the literature on epidemiological studies investigating the impact of aircraft (including the Los Angeles, Munich and Sydney Airport Studies) and road traffic noise on children's blood pressure levels; he concludes that the conclusions given by Evans and Lepore (1993) seem to still hold true:

> *" We know essentially nothing about the long-term consequences of early noise exposure on developing cardiovascular systems. The degree of blood pressure elevations is small. The clinical significance of such changes in childhood blood pressure is difficult to determine. The ranges of blood pressure among noise-exposed children are within the normal levels and do not suggest hypertension. The extent of BP elevations found from chronic exposure are probably not significant for children in their youth, but could portend elevations later in life that might be health damaging."*

Mental Health

4.6.18 The SHE Study investigated the depression and anxiety scores of children; no associations were found between chronic aircraft noise exposure and anxiety and depression in children.

4.6.19 In a review of environmental noise and mental health in children Stansfeld (2000)[6] suggests that although the results of the SEH Study do not show any associations between noise and anxiety or depression, it is possible that noise might affect other more stress-related aspects of mental health such as self-reported stress, social functioning, behavioural adjustment and well-being in children. This possibility is supported by evidence from the Munich Study which showed that aircraft noise was associated with diminished quality of life.

4.6.20 Ristovska (2004)[93] studied children exposed to general environmental noise in an urban setting and examined groups exposed to high and low levels of noise; no differences in anxiety between the two groups were found.

4.6.21 Lercher (2002)[94] has studied the effect of typically experienced ambient environmental noise; he found that noise exposure was associated with small decrements in children's mental health and poorer classroom behaviour.

4.6.22 The RANCH Study found no association between aircraft or road traffic noise and mental health.

4.7 Foetal Effects

Background and WHO Guidelines

4.7.1 In comparison to some other areas of noise and health, there is not an extensive body of scientific literature on the foetal effects of environmental noise exposure. The WHO Guidelines identify foetuses as a vulnerable group in the context of noise exposure, but do not provide any discussion of the potential impact.

4.7.2 In a review of the health effects of noise Morrell (1997)[10] summarises the research on the perinatal effects (e.g. birth weight, birth defects, premature birth) of aircraft noise. He refers to older studies (undertaken in the 1970s and 1980s), which show that birth weight is correlated with aircraft noise exposure; however, he notes that these have been criticised on methodological grounds. Morrell concludes that studies of the effects of aircraft noise on perinatal health have been hampered by serious methodological limitations, it is difficult to draw any conclusions but there appears to be no strong evidence that aircraft noise has significant perinatal effects.

4.7.3 Passchier-Vermeer (2000)[95] has undertaken a review of the effects of noise on foetuses. In relation to environmental noise she considers the effects in terms of those associated with birth outcomes (low birth weight, gestational age, and growth retardation) and abnormalities of the baby that originated during pregnancy. For birth outcomes, she again reports on the older studies (of the 1970s and 1980s) which showed an effect of aircraft noise on birth weight. She also reports on a 1996 Taiwanese study that found no relationship between noise exposure and birth weight (once confounding factors had been taken into account). She notes that the studies of abnormalities of babies are hampered by serious methodological limitations; her conclusion is that although it cannot be excluded, it seems unlikely that environmental noise causes foetal abnormalities.

4.7.4 The HCN Review concludes that there is a lack of evidence for congenital effects of environmental noise.

4.7.5 It is of interest to note that Lercher (2002)[94] found that child self reported mental health was significantly linked to ambient noise level only in children with a history of early biological risk such as low birth rate and preterm birth.

4.8 Health Effects: Conclusions

4.8.1 Reviews by the Institute for Environmental Health (1997)[28] and the HCN (1999)[2] summarised the strength of evidence for various non-auditory effects of environmental noise in tabular format; these are presented in Table 2. For the purposes of this report, a view of the strength of the evidence has been inferred from the WHO Guidelines (1999) is also included in Table 2.

Table 2: Strength of Evidence for Health Effects as Summarised in Recent Reviews

(Note: x = no conclusion drawn on strength of evidence)

Effect	Institute for Environmental Health (1997)	Health Council of the Netherlands (1999)	WHO Guidelines (1999)
Annoyance	Sufficient	Sufficient	Sufficient
Psychiatric Disorders	Inconclusive	Limited	Inconclusive
Cardiovascular and Physiological:			
Ischaemic Heart Disease	Sufficient	Sufficient	Weak Association
Hypertension	Inconclusive	Sufficient	Weak Association
Biochemical Effects	x	Limited	Inconclusive
Immune Effects	x	Limited	Inconclusive
Performance (in adults)	x	Limited	Inconclusive (for environmental noise)
Night-time Effects:			
Sleep Pattern	x	Sufficient	Sufficient
Awakening	Sufficient	Sufficient	Sufficient
Subjective Sleep Quality	Sufficient	Sufficient	Sufficient
Mood Next Day	Sufficient	Sufficient	Sufficient
Performance next Day	Inconclusive	Limited	Sufficient
Immune System	x	Inconclusive	x
Hormones	x	Limited	x
Heart Rate	x	Sufficient	Sufficient
Performance by School Children	Sufficient	Sufficient	Strong enough to warrant further study
Birth Weight	Inconclusive	Limited	x
Congenital Effects	x	Lack	x

4.8.2 Taking into account the summary information in Table 2 and the information from the various recent reviews and papers presented above, it is concluded that the strength of evidence for the various non-auditory effects is as follows:

- **Annoyance**
  Across the scientific literature it is agreed that there is sufficient evidence for environmental noise (and specifically aircraft noise) causing annoyance in those exposed.

- **Mental Health**
  Reviewers generally consider that the evidence for mental health effects is inconclusive or limited. There seems to be a trend emerging of some evidence for mental health symptoms (e.g. depression, anxiety) but not of more severe health problems such as clinically defined psychiatric disorder.

- **Cardiovascular and Physiological**

  In terms of cardiovascular impact there are mixed conclusions from the various reviews and papers on the evidence for effects. Some reviewers consider that there is sufficient evidence, others that the evidence does not convincingly demonstrate an association. Based on existing evidence, it is possible that exposure to aircraft noise may be a risk factor for cardiovascular disease and all would agree that further research is needed to examine the impact of noise on cardiovascular health.

  The scientific literature generally finds that the evidence for long term impact on stress hormone levels is inconclusive or limited.

- **Performance (adults)**

  There is a lack of data on the impact of environmental noise on the performance of adults and no firm conclusions can be drawn.

- **Night-time Effects**

  Across the scientific literature it is agreed that above a certain threshold, environmental noise can cause awakening, and at levels significantly lower, it can also induce sleep stage changes. The threshold level above which effects are found remains a controversial point. There also seems to be general consensus that environmental noise can affect subjective sleep quality, mood the next day and has an acute impact on heart rate. However, as yet, there appears to be no strong/consistent scientific evidence of chronic objective effects (e.g. on stress hormone levels or immune system) or performance the next day.

- **Noise and Children**

  There is a growing body of literature on the impact of aircraft noise on children's health. Across the literature the evidence for the effects of noise exposure on child health is strongest for cognitive effects (particularly reading). Some studies have found that chronically noise exposed children have raised levels of stress, increased blood pressure and mental health effects; however there is still insufficient data to provide unequivocal evidence of such effects.

- **Foetal Effects**

  There has been only very limited research on the effects of environmental noise on foetuses; there is no strong evidence for any effects but it is not possible to draw any firm conclusions.

4.8.3 The WHO NNG (2009) included tables on the observed effect thresholds of noise. The threshold levels for *sufficient* and *limited* evidence were presented.

Sufficient evidence is defined as: A causal relation has been established between exposure to night noise and a health effect. In studies where coincidence, bias and distortion could reasonably be excluded, the relation could be observed. The biological plausibility of the noise leading to the health effect is also well established.

Limited evidence is defined as: A relation between the noise and the health effect has not been observed directly, but there is available evidence of good quality supporting the causal association. Indirect evidence is often abundant, linking noise exposure to an intermediate effect of physiological changes, which lead to the adverse health effect.

Table 3 summarises the sufficient evidence for exposure to night noise and health effects as given in the WHO NNG (2009).

Table 3: Summary of effects and threshold levels for effects where *sufficient evidence* is available (taken from WHO NNG, 2009)

	Effect	Indicator	Threshold, dB
Biological effects	Change in cardiovascular activity	*	*
	EEG awakening	LAmax,inside	35
	Motility, onset of motility	LAmax,inside	32
	Changes in duration of various stages of sleep, in sleep structure and fragmentation of sleep	LAmax,inside	35
Sleep quality	Waking up in the night and/or too early in the morning	LAmax,inside	42
	Prolongation of the sleep inception period, difficulty getting to sleep	*	*
	Sleep fragmentation, reduced sleeping time	*	*
	Increased average motility when sleeping	Lnight, outside	42
Well-being	Self-reported sleep disturbance	Lnight, outside	42
	Use of somnifacient drugs and sedatives	Lnight, outside	40
Medical conditions	Environmental insomnia	Lnight, outside	42

* Although the effect has been shown to occur or a plausible biological pathway could be constructed, indicators or threshold levels could not be determined.

Table 4 summarises the *limited evidence* for which there may be a health effect due to night noise.

Table 4: Summary of effects and threshold levels for effects where *sufficient evidence* is available (taken from WHO NNG, 2009)

	Effect	Indicator	Threshold, dB
Biological effects	Changes in (stress) hormone levels	*	*
Well-being	Drowsiness/tiredness during the day/evening	*	*
	Increased daytime irritability	*	*
	Impaired social contacts	*	*
	Complaints	Lnight, outside	35
	Impaired cognitive performance	*	*
Medical conditions	Insomnia	*	*
	Hypertension	Lnight, outside	50
	Obesity	*	*
	Depression (in women)	*	*
	Myocardial infarction	Lnight, outside	50
	Reduction in life expectancy	*	*
	Psychic disorders	Lnight, outside	60
	(Occupational) accidents	*	*

* Although the effect has been shown to occur or a plausible biological pathway could be constructed, indicators or threshold levels could not be determined.

5. Noise Levels at which Health Effects Occur

5.1 Many of the scientific papers propose threshold noise levels at which various health effects occur and some present exposure response relationships for a range of noise levels. Comparison of such data across the range of research is often not straightforward, as studies are undertaken under different conditions and various units and definitions are used to quantify noise exposures. A full evaluation of the scientific literature to investigate noise levels at which it is suggested that various effects occur was beyond the scope of this review. However, others have proposed various noise level 'thresholds' for health effects; the threshold levels for effects presented in WHO Guidelines observational thresholds from the HCN Review and evaluation criteria developed by Griefahn (2004)[96] and Scheuch (2003)[97] specifically for airports are presented below.

WHO Guidelines

5.2 The WHO Guidelines present guideline values for the onset of various degrees of annoyance, the lowest level at which effects would occur for sleep disturbance in the general population, and disturbance of information extraction for school class rooms. These are summarised in Table .

5.3 The WHO Guidelines (1999) conclude, that generally it is not possible to establish exposure response relationships for the various health effects as the scientific literature is limited. Although, a more recent WHO meeting held in 2002[98] which brought together a group of international experts to examine exposure response relationships of noise and health, concluded that data is now available upon which exposure response curves for various sleep disturbance and cognitive effects could be produced.

5.4 The WHO Guidelines also observe, that the most widely studied exposure response relationship is that between noise and annoyance. Since the publication of the WHO guidelines further analyses to identify relationships between noise from road, rail and aircraft and annoyance have been derived by Miedema and Ondshoorn (2001)[23] an evaluation of these relationships by Kempen (2005)[99] concluded that they were suitable for health impact assessment. The WHO 2002 meeting noted that there were exposure response curves available for noise and annoyance.

HCN Review

5.5 Observational thresholds[*] for the health outcomes (for which it was considered there was sufficient evidence of effects – see Table 2) are presented in the HCN Review and are reproduced in Table 4.

5.6 Since the HCN report was published Babisch (2005[100] and 2006[92]) has undertaken a review on the relationship between transportation noise and cardiovascular risk. Based on this review he undertook a meta-analysis and concluded that below 60 dBA $L_{eq06\text{-}22\ hour}$ for road traffic noise there is no increase in IHD (mycardial infarction) but that above 60 dBA $L_{eq06\text{-}22\ hour}$ the risk increases continuously.

[*] Observational thresholds represent the lowest noise exposure levels above which generally in well designed epidemiological studies the effect has been observed in the average population of adults or other average population as specified (e.g. children).

Table 5: WHO Guideline Values and Observational Thresholds Proposed by HCN

Effect	Who Guidelines(1999) Guideline Values			HCN (1999) Observational Threshold		
	Measure	Value	Indoor/ Outdoor	Measure	Value	Indoor/ Outdoor
Annoyance	dBA Leq_{16hour} Moderate Annoyance	50	Outdoor	Ldn Severe Annoyance	42	Outdoor
	Serious Annoyance	55	Outdoor			
	Moderate Annoyance	35	Indoor			
IHD				dBA $Leq_{06\text{-}22\ hour}$	70	Outdoor
Hypertension				dBA $Leq_{06\text{-}22\ hour}$	70	Outdoor
Night-time Effects						
Sleep Disturbance	dBA Leq_{8hour}	30	Indoor			
	dBA Lmax	45	Indoor			
	dBA Leq_{8hour}	45	Outdoor			
	dBA Lmax	60	Outdoor			
Awakening				SEL	50	Indoor
Sleep Stages				SEL	35	Indoor
Subjective Sleep Quality				dBA Leq_{night}	40	Outdoor
Heart Rate				SEL	40	Indoor
Mood Next Day				dBA Leq_{night}	<60	Outdoor
Performance by School Children	dBA $Leq_{during\ class}$	35	Indoors	dBA Leq_{school}	70	Outdoor

5.7 A cursory look at the data in Table 5 indicates that even for these two reviews comparison of the values is not straightforward because of the use of different metrics, time bases and conditions (e.g. indoor versus outdoor noise levels).

Griefahn and Scheuch Evaluation Criteria

5.8 Based on an extensive review of the literature Griefahn and Scheuch suggest 'evaluation criteria' specifically for aircraft noise exposure to protect those living in the vicinity of civil airports. The purpose of these criteria is to provide guidance on the noise levels at which control measures need to be introduced, to protect communities around airports from the potential adverse health effects of noise. Griefahn and Scheuch propose a three tier hierarchy of criteria:

- Critical limits – above these levels there is a risk of health effects and such levels should only be tolerated as an exception for a limited time. Above these levels noise it is imperative that noise control measures should be introduced.
- Protection Guides – Exposure below these levels should not induce adverse health effects in the average person, although sensitive groups may still be affected. These are the 'central assessment values' above which action should be taken to reduce noise exposure.

- Threshold Values – inform about measurable physiological and psychological reactions to noise exposure where long term adverse health effects are not expected. To increase quality of life these values constitute a long term goal.

5.9 Griefahn and Scheuch's proposed Critical Limits, Protection Guides and Threshold Values for sleep disturbance, annoyance and cardiovascular disease are shown in Table 6. It can be seen that the proposed Threshold Values for annoyance and sleep disturbance are in alignment with the WHO threshold guideline levels. Griefahn[83] notes that although the WHO Guideline Values and proposed Threshold Values provide a long-term goal, achieving them around airports is currently practically impossible without complete cessation of aircraft movements. The Protection Guides and Critical Limits provide more practical 'tolerable limits' for the avoidance of adverse health effects in those living in the communities around civil airports.

Table 6: Griefahn and Scheuch's proposed Critical Limits, Protection Guides and Threshold Values for Sleep Disturbance, Annoyance and Cardiovascular Disease

Effect	Evaluation Criteria	Measure	Value	Indoor/ Outdoor
Sleep Disturbance*	Critical Limit	dBA $L_{max\ 22\text{-}06\ hour}$	6 events at 60 dBA	Indoor
	Critical Limit	$L_{eq\ 22\text{-}06\ hour}$	40	Indoor
	Protection Guide	dBA $L_{max\ 22\text{-}06\ hour}$	13 events at 53 dBA	Indoor
	Protection Guide	dBA $L_{max\ 22\text{-}01\ hour}$	8 events at 56 dBA	Indoor
	Protection Guide	dBA $L_{max\ 01\text{-}06\ hour}$	5 events at 53 dBA	Indoor
	Protection Guide	dBA $L_{eq\ 22\text{–}06\ hour}$	35	Indoor
	Protection Guide	dBA $L_{eq\ 22\text{-}01\ hour}$	35	Indoor
	Protection Guide	dBA $L_{eq\ 01\text{-}06\ hour}$	32	Indoor
	Threshold Value	dBA $L_{max\ 22\text{-}06\ hour}$	23 events at 40 dBA	Indoor
	Threshold Value	dBA $L_{eq\ 22\text{-}06\ hour}$	30	Indoor
High Annoyance**	Critical Limit	dBA $L_{eq\ 06\text{-}22\ hour}$	65	Outdoor
	Protection Guide	dBA $L_{eq\ 06\text{-}22\ hour}$	62	Outdoor
	Threshold Value	dBA $L_{eq\ 06\text{-}22\ hour}$	55	Outdoor
Chronic Disease **	Critical Limit	dBA $L_{max\ 06\text{-}22\ hour}$	19 events at 99 dBA	Outdoor
	Critical Limit	dBA $L_{eq\ 06\text{-}22\ hour}$	70	Outdoor
	Protection Guide	dBA $L_{max\ 06\text{-}22\ hour}$	25 events at 90 dBA	Outdoor
	Protection Guide	dBA $L_{eq\ 06\text{-}22\ hour}$	65	Outdoor

Note:
* Griefahn and Scheuch suggest that if it is not possible to have no aircraft movements during the night, then concentrating air traffic to the first part of the night is preferable, as people are less sensitive to noise during the 22.00 to 01:00 hours time period and disturbances during the early part of the night can be compensated for in the following quieter period. They therefore propose different Protection Guide levels for the earlier and later part of the night as shown above.
** Griefahn and Scheuch found that the data were not strong enough to establish maximum level (Lmax) evaluation criteria for annoyance or Threshold Values for chronic disease.

5.10 The WHO NNG (2009) concluded that below 30dB $L_{night,\ outside}$, no effects on sleep are observed except for a slight increase in the frequency of body movements during sleep due to night noise. It was concluded that there is no sufficient evidence that the biological effects observed at the level below 40dB $L_{night,\ outside}$ are harmful to health.

The relationship between night noise exposure and health effects as summarised in the WHO NNG (2009) are presented in Table 7.

Table 7: Effects of different levels of night noise on the population's health (taken from the WHO NNN, 2009)

Average night noise level over a year $L_{night, outside}$	**Health effects observed in the population**
Up to 30dB	Although individual sensitivities and circumstances may differ, it appears that up to this level no substantial biological effects are observed. $L_{night,outside}$ of 30dB is equivalent to the no observed effect level (NOEL) for night noise.
30 to 40dB	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 (for example children, the chronically ill and the elderly) are more susceptible. However, even in the worst cases the effects seem modest. $L_{night, outside}$ of 40dB is equivalent to the lowest observed adverse effect level (LOAEL) for night noise.
40 to 55dB	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.
Above 55dB	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.

5.11 The WHO night noise guideline (NNG) is recommended for the protection of public health from night noise as **40dB $L_{night, outside}$** with an interim target of **55dB $L_{night, outside}$**. It is explained that the interim target is recommended in the situations where the achievement of the NNG is not feasible in the short-term for various reasons. The interim target is not a health-based limit value by itself and vulnerable groups cannot be protected at this level.

Conclusion

5.12 Agreement upon threshold noise levels that assure effective protection of the health of the population from aircraft noise remains controversial; this is particularly true for protection of rest and sleep at night. The most widely studied exposure response relationship is that between noise and annoyance; based on data from numerous social survey studies of public reactions to transport noise, dose-response relationships for noise and annoyance have been proposed.

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