The Effect of Nocturnal Aircraft Noise on Health: a Review of Recent Evidence.

Charlotte Clark & Stephen A Stansfeld
Barts & the London School of Medicine, Queen Mary, University of London

Report prepared for the London Borough of Hounslow

September 2011

Final Version

Table of Contents

ABBREVIATIONS & GLOSSARY

95%CI	95% confidence interval demonstrating the estimated range of an odds ratio
DALYS	Disability adjusted life years: measure used in the World Health Organisation Burden of Disease methodology
dBA	A measure of sound level in decibels, A-weighted to approximate the typical sensitivity of the human ear
ECG	Electrocardiography: records heart rhythm
EEG	Electroencephalography: records brain waves
EMG	Electromyography: records muscle activity
EOG	Electroculograph: records eye movements
LA_{eq16}	Average sound pressure level for a specified period (in this example 16 hours) in dBA units
L_{Amax}	Maximum sound pressure in dBA units
LC_{pk}	measurement of peak sound pressure level over a specified period
NREM	Non-rapid eye movement sleep
OR	Odds ratio
PSG	Polysomnography: records biophysiological changes that occur during sleep
REM	Rapid eye movement sleep
SEL	Sound exposure level

EXECUTIVE SUMMARY

SCOPE OF THE REVIEW

This literature review was carried out to inform the London Borough of Hounslow's response to the Department for Transport's 'Developing a Sustainable Framework for UK Aviation: Scoping Document' (Department for Transport, 2011), which forms a platform and consultation for debate about the future development of aviation in the UK. Whilst aviation plays a significant role in economic growth in the UK, this has to be balanced with effects on climate change and the quality of life of local communities. This consultation seeks debate and opinion about night flying regimes around Heathrow, Gatwick and Stansted airports. In response, this literature review focuses on nocturnal aircraft noise exposure, summarising current evidence for effects of nocturnal aircraft noise exposure on human health. Effects for both adults and children are described.

NON-AUDITORY EFFECTS OF NOCTURNAL AIRCRAFT NOISE

Overall, evidence for an effect of aircraft noise exposure on human health has strengthened in recent years, as more methodologically robust studies have been carried out. Methodological advancements have included the use of larger epidemiological community samples, as well as better characterisation of noise exposure. This has enabled recent studies to begin to differentiate the effects of nocturnal aircraft noise exposure (usually defined as 23.00-07.00 hours) from the effects of daytime aircraft noise exposure (usually defined as 07.00-23.00 hours). Two main pathways for how nocturnal aircraft noise exposure could influence health have been postulated. Firstly, noise can cause sleep disturbance, which could lead to fatigue, annoyance, low mood and impaired performance the next day. Secondly, nocturnal noise exposure may have a direct effect by activating biological systems which could have long-term effects on health: e.g by increasing heart rate or altering cortisol responses.

NOCTURNAL AIRCRAFT NOISE, HYPERTENSION & CORONARY HEART DISEASE

Evidence for an effect of aircraft noise on coronary heart disease has increased in recent years. A range of outcomes ranging from self-reported hypertension and medication use, to more objective measures of blood pressure, as well as incidence of myocardial infarction and ischaemic heart disease have been examined. Overall, as well as there being consistent evidence for a small but significant impact of aircraft noise exposure on cardiovascular risk and disease, this research area is one of the few that can draw specific conclusions about the effect of nocturnal aircraft noise exposure.

The European Union funded HYENA study (Hypertension and Exposure to Noise near Airports) (Jarup *et al.*, 2008), a large community study of samples from around 7 major European airports including London Heathrow, found that a 10 dBA increase in nocturnal aircraft noise exposure was associated with a 14% increase in odds for hypertension, which was defined as a systolic blood pressure ≥140 or a diastolic blood pressure ≥90 or a diagnosis of hypertension by a physician in conjunction with use of antihypertensive medication. No effect was found for day-time aircraft noise exposure. Overall, the findings of the HYENA study indicate specific effects of nocturnal aircraft noise exposure on hypertension, as well as suggesting that residents around London Heathrow airport may be more vulnerable to the effects of noise compared to those from other European countries. Similarly, the European Union funded RANCH project (Road traffic and Aircraft Noise exposure and children's Cognition and Health) of 9-10 year old children living near London Heathrow and Amsterdam Schiphol found that day-time and nocturnal aircraft noise exposure at home was associated with systolic and diastolic blood pressure (van Kempen *et al.*, 2006). Taken as whole, the evidence for hypertension and coronary heart disease would support preventive measures to reduce nocturnal aircraft noise exposure.

NOCTURNAL AIRCRAFT NOISE & SLEEP DISTURBANCE

There is consensus that nocturnal aircraft noise is associated with sleep disturbance. However, the measurement of sleep disturbance is challenging: no one measure is considered accurate or reliable, thus, a broad range of sleep outcomes have been examined, ranging from weaker subjective outcomes such as self-reported sleep disturbance, to more objective measures such as polysomnography (PSG), which records biophysiological changes that occur during sleep, and actigraphy, which measures sleep disturbance based on body movements.

There is sufficient evidence from laboratory and community studies that aircraft noise disturbs sleep in adults, as evidence by an increased number of awakenings, increased length of awakenings, reduced slow-wave sleep and Rapid Eye Movement sleep, as well as effects on subjective self-reported sleep quality. There is also consensus that nocturnal noise exposure causes direct biological responses such as changes in heart rate and blood pressure, which could also influence health in the longer-term. Whilst this evidence supports regulatory policy for night-time noise exposure, it must be acknowledged that a few studies do not find an effect of aircraft noise on sleep disturbance. The majority of evidence in this field comes from cross-sectional studies which are unable to examine the long-term health effects of aircraft noise disturbed sleep or mechanisms for effects. There is a lack of knowledge concerning the effects nocturnal aircraft noise on children's sleep outcomes. To date few studies have examined changes in sleep disturbance associated with either a reduction or increase in nocturnal noise caused by changes in airport operations and evidence from such studies is equivocal.

Whilst there remain some gaps in knowledge, there is thought to be sufficient data available to define defining limit values and guidelines for nocturnal noise exposure. The World Health Organisation Europe 'Night Noise Guidelines' (NNG), are the result of deliberations of international experts, which aim to provide clear guidance for planners and policy makers within Europe. The working group agreed that there was sufficient evidence that nocturnal noise exposure was related to self-reported sleep disturbance, medication use, and self-reported health problems and that there was some evidence along with biological plausibility for effects of nocturnal noise exposure on hypertension, myocardial infarctions, and depression. The NNG state that the target for nocturnal noise exposure should be 40 dB $L_{night,\ outside}$, which should protect the public as well as vulnerable groups such as the elderly, children, and the chronically ill from the effects of nocturnal noise exposure on health. The NNG also recommend the level of 55 dB $L_{night,\ outside}$, as an interim target for countries wishing to adopt a step-wise approach to the guidelines.

NOCTURNAL AIRCRAFT NOISE & STRESS HORMONES

It has been postulated that aircraft noise exposure could influence the stress hormones adrenaline, noradrenaline and cortisol, which are released by the adrenal glands in situations of stress. Studies in this field have demonstrated conflicting results, most likely because these hormones can be extremely difficult to study. The most compelling evidence for effects of aircraft noise effects on adult endocrine responses seen to date comes from a sub-study of the HYENA study, which found an effect of nocturnal, as well as 24 hour and day-time aircraft noise exposure on increased morning cortisol for women but not men (Selander *et al.*, 2009). Analyses also suggested that this effect was stronger in the London Heathrow sample compared with other European countries. Further studies on the effects of nocturnal aircraft noise exposure on endocrine responses in both adults and children are required. It should also be noted that there remains a lack of understanding about how long-term activation of the endocrine system links to health impairment and also about whether endocrine responses can habituate to noise exposure.

NOCTURNAL AIRCRAFT NOISE & ANNOYANCE

Annoyance is the most widespread response to noise and describes negative reactions such as disturbance, dissatisfaction, and irritation. Overall, there is consistent evidence that aircraft noise annoyance responses around major European airports have increased in recent years. In terms of London Heathrow airport specifically, there is evidence from methodologically strong studies that day-time aircraft noise annoyance is higher than that observed around other English airports (Le Masurier *et al.*, 2007), as well as evidence that both day-time and nocturnal aircraft noise annoyance is higher than that observed around other European airports (Babisch *et al.*, 2009). Taken as a whole, the evidence suggest that the population around London Heathrow may be especially vulnerable to annoyance responses, which would have implications if aircraft noise exposure were to increase due to changes in airport operations.

NOCTURNAL AIRCRAFT NOISE & COGNITIVE DEVELOPMENT

Overall, evidence for the effects of aircraft noise exposure on children's cognition has strengthened in recent years, showing effects of day-time or 24 hour aircraft noise exposure on children's reading comprehension and memory. To date, few studies have focused specifically on the effects of nocturnal aircraft noise exposure on children's cognitive performance. Recent secondary analyses of the London Heathrow sample of children from the RANCH project compared the effects of day-time aircraft noise exposure at school with nocturnal aircraft noise exposure at home on cognitive performance (Stansfeld *et al.*, 2010). This study found that whilst nocturnal aircraft noise exposure at home was associated with impaired reading comprehension and recognition memory, nocturnal aircraft noise exposure had no additional effect on these outcomes, once day-time exposure at school had been taken into account. These findings suggest that the school should be the main focus for the protection of children against the effects of aircraft noise on cognitive performance.

NOCTURNAL AIRCRAFT NOISE, PSYCHOLOGICAL MORBIDITY & WELL-BEING

Studies of aircraft noise exposure and psychological health have used day-time or 24 hour noise exposure metrics making it hard to establish the effects of nocturnal aircraft noise exposure, per se. Psychological ill-health has been examined using a range of outcomes including psychiatric diagnoses, the number of psychological symptoms, medication use, as well as questionnaire assessments of well-being and quality of life. Overall, the evidence for both adults and children suggests that aircraft noise exposure is probably not associated with serious psychiatric disorder, but that there may be effects on psychological symptoms, well-being, and quality of life. However, this conclusion is largely drawn from studies of day-time aircraft noise exposure and evidence in relation to nocturnal aircraft noise exposure is lacking. There may be a stronger link to psychiatric disorder for nocturnal noise exposure and further contemporary studies need to explore this issue in large scale longitudinal studies using standardised interview measures of psychiatric disorder.

CONCLUSION

This review indicates that nocturnal aircraft noise exposure is potentially associated with considerable public health impact for residents living near major airports. Evidence for an effect of nocturnal aircraft noise exposure on human health has strengthened over the past decade and there is good and robust evidence for an effect of nocturnal aircraft noise exposure on hypertension, sleep disturbance, and noise annoyance. This evidence is sufficient to support preventive measures such as policy, guidelines, and limit values for nocturnal aircraft noise exposure in communities near airports. The need for a preventive approach is further strengthened by the evidence from several recent studies which indicate that the population around Heathrow airport may be particularly vulnerable to effects of nocturnal aircraft noise on health. Night-time flying regimes around London Heathrow airport need to balance the economic benefits against the protection of public health and quality of life in the surrounding area.

1 INTRODUCTION

1.1. SCOPE OF THE REVIEW

This literature review was carried out to inform the London Borough of Hounslow's response to the Department for Transport's 'Developing a Sustainable Framework for UK Aviation: Scoping Document' (Department for Transport, 2011), which forms a platform and consultation for debate about the future development of aviation in the UK. Whilst aviation plays a significant role in economic growth in the UK, this has to be balanced with effects on climate change and the quality of life of local communities. This consultation seeks debate and opinion about night flying regimes around Heathrow, Gatwick and Stansted airports. In response, this literature review summarises the current evidence for effects of aircraft noise on human health, focusing specifically on effects for nocturnal aircraft noise exposure.

This is a narrative review, focusing on key studies in the field conducted over the past decade, summarising recent developments in knowledge. The literature has been identified from searches of electronic databases including PubMed, IngentaConnect, Science Direct, Google Scholar, and the Acoustical Society of America Digital Library, as well as through searches of reference lists of papers, and searches of specific journals including 'Noise and Health' and the 'Journal of the Acoustical Society of America', as well as conference proceedings such as INTERNOISE and ICBEN (International Commission on the Biological Effects of Noise). This strategy has been supplemented by the research teams' knowledge of existing reports and publications. The literature is predominantly drawn from Europe and the USA, with a focus on UK-relevant publications, where possible. The review focuses on studies of aircraft noise exposure, where possible, but does draw on findings of other noise sources such as road traffic noise, where the evidence may be relevant.

This review considers the characterisation of noise exposure in these studies and then reviews the findings of epidemiological studies which focus on the role of chronic nocturnal aircraft noise on hypertension and coronary heart disease; sleep disturbance; stress hormones; annoyance; cognitive development; and psychological morbidity and well-being. The review additionally considers evidence from laboratory studies, where this adds further to our knowledge and understanding of nocturnal noise effects on health. Studies of adults and children are included.

1.2. BACKGROUND TO THE RESEARCH FIELD

The direct effect of sound energy on human hearing is well established and accepted (Babisch, 2005, Kryter, 1985). Auditory impairments are typically seen in certain industrial occupations, hence protective legislation requiring hearing protectors to be worn. In contrast, non-auditory effects of noise on human health are not the direct result of sound energy. Instead these effects are the result of noise as a general stressor: thus the use of the term noise not sound: noise is unwanted sound. The non-auditory effects of noise are less well established and accepted than auditory effects. Overall, evidence for an effect of aircraft noise exposure on human health has strengthened in recent years, as more methodologically robust studies have been carried out. Methodological advancements in the field have included the use of larger epidemiological community samples as well as better characterisation of noise measurement and better measurement of health. Studies have also examined exposure-effect relationships, and have attempted to identify thresholds for noise effects on health which can be used to inform guidelines for noise exposure. There has also been a better assessment of confounding factors: noise exposure and health are often confounded by socioeconomic position; individuals living in poorer social circumstances are more likely to have poorer health, as well as be exposed to noise. Therefore, measures of socioeconomic position need to be taken into account when examining associations between noise exposure and health. Evidence from longitudinal studies is also beginning to emerge and a few recent studies have differentiated nocturnal aircraft noise exposure from day-time aircraft noise exposure to examine the specific health effects associated with exposure during different parts of the day.

It is increasingly been thought that the night-time period, when the organism physically recovers from daytime load and when brain restoration takes place, may be particularly important with respect to noise-induced health effects (Babisch, 2011). Nocturnal aircraft noise could affect health in two ways. Firstly, by a direct effect on biological systems, such as increasing heart rate, awakenings and sleep quality, as the individual responds to stimuli in the environment (HCN, 2004). Activation of some biological responses could have long-term effects on physical and mental health (Hume, 2011a). Secondly, sleep disturbance could impact on well-being, causing annoyance, irritation, low mood, fatigue, and impaired task performance (HCN, 2004).

2 THE ASSESSMENT OF NOISE EXPOSURE

Studies of noise effects on health typically use established metrics of external noise exposure, which indicate the average sound pressure for a specified period using dBA as the measurement unit (dBA is the unit of A-weighted sound pressure level where A-weighted means that the sound pressure levels in various frequency bands across the audible range have been weighted in accordance with differences in human hearing sensitivity at different frequencies). The introduction of the European Union's Environmental Noise Directive Metrics (END) (Directive 2002/49/EC, 2002) has further led to a more standardised approach within the research field to the measurement and characterisation of noise exposure.

The metrics typically used are:

- L_{Aeq16} which indicates noise exposure over a 16 hour daytime period usually 07.00-23.00. This same time period is also sometimes represented by L_{day} which indicates noise exposure over a 12 hour day-time period, usually 0700-19.00 and $L_{evening}$ which indicates noise exposure during 4 hours of the evening, typically 19.00-23.00.
- L_{night} which indicates noise exposure at night usually 23.00-07.00.
- The END uses the metric L_{den} (day-evening-night level) which combines the L_{day}, $L_{evening}$ and L_{night} measures to indicate average noise exposure over the 24 hour period, with a 5dB penalty added to the evening noise measure and a 10dB penalty added to the night-time noise measure to account for the greater sensitivity of people to evening and nocturnal noise exposure .

In contemporary studies these metrics are usually modelled using standard airport noise modelling systems, using Geographical Information Systems to present the data, whilst fewer studies measure noise exposure in the community, which can be less reliable if measurements cover short time-periods. A few recent studies have also examined exposure to maximum noise levels (e.g. L_{Amax}), as in pathophysiological terms it is not known whether the overall 'dose' of noise exposure is important in determining effects on health or whether peak sound pressure events or the number of noise events might be important. This issue is of increasing importance given that the number of noise events for aircraft and road traffic noise are increasing, while noise emission levels per event are falling.

Studies of the non-auditory effects of noise exposure typically use the term 'noise' to refer to the individual's exposure to sound. The term noise is used, regardless of whether the exposure is high or low: the term noise implies that the sound exposure is unwanted and that it is an environmental stressor. This tradition is maintained throughout this literature review.

3 NOCTURNAL AIRCRAFT NOISE EXPOSURE & HEALTH EFFECTS

3.1. Hypertension & Coronary Heart Disease

Studies examining the effects of aircraft noise on coronary heart disease (CVD) and coronary risk factors in adults have used varying outcome measures, ranging from self-report measures of hypertension and medication use to more objective measures of blood pressure as well as prevalence and incidence of myocardial infarction and ischaemic heart disease. Methodologically robust studies also take important confounding factors associated with coronary heart disease such as age, gender, smoking, and body mass index into account.

A meta-analysis of evidence in this field found that whilst evidence for effects of aircraft noise exposure on cardiovascular risk has increased in recent years , few studies have specifically examined night-time aircraft noise exposure (Babisch, 2006). Thus, evidence for effects of night-time aircraft noise exposure has to be gleaned from studies using either day-time or 24 hour aircraft noise metrics. For example, one meta-analysis found that a 5 dBA L_{Aeq16} rise in aircraft noise was associated with a 25% increase in risk of hypertension compared with those not exposed to aircraft noise (van Kempen *et al.*, 2002). Further, an effect of aircraft noise on incidence of myocardial infarction has been demonstrated for individuals exposed to >50 $L_{Aeq24\ hours}$, with stronger associations found for older subjects (Eriksson *et al.*, 2007). Aircraft noise has also been associated with death from myocardial infarction in the very large Swiss National cohort Study with a dose-response relationship for both level and duration of exposure. Moreover, this association was not explained by confounding factors such as education, area socioeconomic status or particulate air pollution (Huss *et al.*, 2010). Results were similar when comparing day time or night time exposures.

Recent years have seen studies begin to quantify the specific effect of night-time aircraft noise exposure on cardiovascular health. A large-scale study of the prescription data of 809,379 people around Cologne-Bonn airport demonstrated an effect of nocturnal aircraft noise exposure (based on a 6-month average exposure between 03.00-05.00 hours) on the use of anti-hypertensive drugs and cardiovascular drugs, especially when prescribed in conjunction with anxiolytic drugs (Greiser *et al.*, 2007). However, this study has several methodological limitations: no data about individual level confounding socioeconomic and health factors such as income, homeownership, length of residency, health status, and existing illness were included in the analyses.

The European Union funded HYENA study (HYpertension and Exposure to Noise near Airports) assessed the relationship between aircraft and road traffic noise near airports and the risk of hypertension (Jarup *et al.*, 2008), differentiating the effect of aircraft noise exposure in the day-time and night-time. This study measured the blood pressure of 4681 people aged 45-70 years who had lived for at least 5 years near one of 7 major European airports (Heathrow, London; Schiphol, Amsterdam; Tegel Berlin, Arlanda, Stockholm; Bromma, Stockholm. Malpensa, Milan, and Elephterios Venizelos, Athens). The study found a significant exposure-response relationship between night-time aircraft noise exposure (L_{night} defined as 2300-0700 hours) and risk of hypertension (defined as a systolic blood pressure ≥140 or a diastolic blood pressure ≥90 or a diagnosis of hypertension by a physician in conjunction with use of antihypertensive medication), after adjustment for major confounding factors including gender, age, education, physical activity levels, alcohol intake, and body mass index. A 10dBA increase in night-time aircraft noise exposure was associated with a 14% increase in odds for hypertension. Aircraft noise exposure during the day (L_{Aeq16} defined as 0700-2300 hours) was not associated with hypertension. These findings did not differ by gender or across the 6 countries examined. The authors speculate that there could be an effect for nocturnal but not day-time aircraft noise exposure as nocturnal aircraft noise may influence hypertension by causing acute physiologic responses that may affect restoration during sleep. However, there may also be a methodological explanation as aircraft noise exposure is based on place of residence making it possible that nocturnal aircraft noise had less exposure misclassification than day-time aircraft noise exposure which assessed the period when people were more likely to be absent from their homes.

A further HYENA paper examined associations between aircraft noise exposure and medication use, assessing a range of common prescriptions: anti-hypertensives, antacids, anxiolytics, hypnotics, antidepressants, anti-asthmatics; finding an effect of nocturnal aircraft noise on anti-hypertensive use, but only for the UK and the Netherlands samples (Floud *et al.*, 2011). In the UK, a 10dB increase in nocturnal aircraft noise was associated with a 34% increase in odds of taking anti-hypertensives. This paper also found an effect for anxiolytic medication in all 6 countries, with a 10 dBA increase in nocturnal aircraft noise being associated with a 27% increase in odds of taking anxiolytic medication. Anxiolytics are used to treat anxiety but are also prescribed for sleep problems.

The HYENA study is methodologically strong, using aircraft noise exposure from 2002 to assess health outcomes assessed 5 years later, adjusting for a range of confounding factors. With its large sample from around London Heathrow airport, the HYENA study has direct policy relevance for the UK. However, one limitation of the HYENA study is that it is cross-sectional: it is therefore possible that the poorer health outcomes and the medication use may have preceded the noise exposure (Floud *et al.*, 2011). However, taken as a whole, the results of the HYENA study indicate specific effects of nocturnal aircraft noise exposure on hypertension, and on anti-hypertensive use, and the findings suggest that the UK sample may be particularly vulnerable to these effects: the UK sample shows stronger associations between nocturnal aircraft noise and health, based on aircraft noise exposure in 2002 around London Heathrow airport, than those observed in the other European countries. This does not seem to be explained by the number of night-flights, as Amsterdam Schiphol and Elephterios Venizelos, Athens airports have a similar, if not slightly higher number of night-flights compared with London Heathrow (EUROCONTROL, 2009). The HYENA study concluded that preventive measures should be considered to reduce night-time noise from aircraft (Jarup *et al.*, 2008).

As aircraft noise exposure shows an association with cardiovascular disorders such as hypertension, it has also been hypothesised that associations may be observed with stroke, which is another ischaemic outcome. A population-based cohort study of over 57,000 people in Denmark found that the incidence rate ratio for stroke increase by 14% for a 10dB L_{den} increase in road traffic noise (Sørensen *et al.*, 2011). Death from stroke was not associated with aircraft noise exposure in the Swiss National Cohort Study although further study is needed of haemorrhagic as well as ischaemic stroke separately (Huss *et al.*, 2010). Whilst this is an emerging field of study, stroke is a fairly rare outcome in the population, making robust studies of associations only possible on studies involving tens of thousands of participants.

Evidence for effects of noise on coronary risk factors in children has been mixed, which may be due to a number of methodological problems including lack of control for confounding factors such as parental blood pressure, socioeconomic status, age, and body composition; differences in study design; and methodological differences in the assessment of blood pressure and noise exposure (Paunovic *et al.*, 2011). However, overall, studies show a tendency towards a positive relationship between aircraft noise exposure and blood pressure in children (Paunovic *et al.*, 2011). The sub-study of RANCH project around Amsterdam Schiphol and London Heathrow airports found an effect of aircraft noise during the daytime at home (L_{Aeq16}), as well as nocturnal aircraft noise exposure ($L_{Aeq\ night}$) on systolic and diastolic blood pressure for 9-10 year old children but no effect for day-time aircraft noise at school (L_{Aeq16}) (van Kempen *et al.*, 2006). These findings suggest that it may specifically be aircraft noise exposure during the night that affects children's blood pressure. However, these findings need replication in different settings and samples before more definite conclusions can be drawn about the effects of nocturnal aircraft noise exposure on children's blood pressure. It is also worth noting that most studies that find an effect of aircraft noise on children's blood pressure find relatively small differences in blood pressure measurements, which are well within the normal range (Paunovic *et al.*, 2011): whether such changes in blood pressure have long-term consequences for health is not well understood for this age group.

Overall, as well as there being consistent evidence for a small but significant impact of aircraft noise exposure on cardiovascular risk and disease, this research area is one of the few that can draw specific conclusions about the effect of nocturnal aircraft noise exposure. The findings of the HYENA study indicate specific effects of nocturnal aircraft noise exposure on hypertension, as well as suggesting that residents around London Heathrow airport may be more vulnerable to the effects of noise compared to those from other European countries. Taken as whole, the evidence for hypertension and coronary heart disease would support preventive measures to reduce nocturnal aircraft noise exposure.

3.2. Sleep Disturbance

Overall, there is evidence for an effect of nocturnal aircraft noise on sleep disturbance from community based studies of noise exposed populations (HCN, 2004, Hume, 2011a, Miedema and Vos, 2007). However, some reviews conclude that the evidence is inconclusive and contradictory (Jones, 2009, Michaud *et al.*, 2007), which could be explained by methodological differences between studies of noise effects on sleep disturbance (Clark and Stansfeld, 2007).

The measurement of sleep disturbance is challenging, as no single physical, physiological or psychological measure is considered accurate or reliable compared with polysomnography, which is expensive and not suitable for large field studies. Studies have examined a broad range of sleep disturbance outcomes, ranging from weaker subjective outcomes such as self-reported sleep disturbance, to more objective measures such as polysomnography (PSG) which records biophysiological changes that occur during sleep , including brain waves using electroencephalography (EEG), eye movements using electroculography (EOG), muscle activity using electromyography (EMG), and heart rhythm using electrocardiography (ECG), and wrist-actimetry, which measures sleep disturbance based on limb movements.

Michaud's recent review identified a range of sleep outcomes which have been examined for aircraft noise exposure including interference with ability to fall asleep, shortened sleep duration, awakenings, increased bodily movements and perceived quality of sleep (Michaud *et al.*, 2007). Self-reported sleep disturbance outcomes are potentially particularly vulnerable to bias, as such measures are likely to be influenced by noise annoyance, noise sensitivity, attitudes to the noise source, psychological health, psychosocial stress, age, and other individual factors. Effects of noise on self-reported sleep disturbance may indicate noise annoyance per se, rather than a direct effect of noise exposure on sleep outcomes. Many studies which use self-reported sleep disturbance use fairly weak measures, often relying on single item questions. A meta-analysis of 24 field studies, including almost 23,000 individuals exposed to night-time noise levels ranging from 45-65dBA, found that aircraft noise was associated with greater self-reported sleep disturbance than road traffic, and road traffic noise with greater disturbance than railway noise (Miedema and Vos, 2007). A recent laboratory study also found that aircraft noise was associated with greater self-reported sleep disturbance than road traffic noise, but, contrastingly, for objective measures of sleep disturbance, road traffic noise was associated with greater disturbance than aircraft noise (Basner *et al.*, 2011). Miedema & Vos's meta-analysis also found inverted U-shaped association between rail, road traffic, and aircraft noise exposure and self-reported sleep disturbance, with the greatest disturbance being found for individuals aged 50-56 years. Miedema & Vos's study concluded that transportation noise was a widespread factor affecting sleep.

Objective assessments of sleep outcomes observed using EEG, assess noise effects on the different stages of the sleep cycle. The average sleep cycle last between 90 to 110 minutes, and an individual experiences between four to six sleep cycles per night (Michaud *et al.*, 2007). Non-rapid eye movement (NREM) sleep has four stages; stage 1 is a light stage of sleep which lasts 5-10 minutes, acting as a bridge between wakefulness and sleep; stage 2, another light stage of sleep, lasts around 20 minutes and is characterised by brain waves of increased frequency and increased heart rate variability; stage 3 sees the transition to deeper stages of sleep, and is characterised by an increased amount of delta waves of lower frequency; stage 4 is the deepest stage of sleep, characterised by a greater preponderance of delta waves (>50% of the sleep scoring epoch). NREM is followed by Rapid Eye Movement (REM) sleep, which is characterised by rapid eye movements (slow eye movements are found in stage 1), as well as increases in brain activity and greater variability in respiration rate, blood pressure and heart rate. REM sleep typically starts 70-90 minutes after falling asleep, although each sleep cycle does not have to include all the stages of sleep. Often people will move between the NREM sleep stages several times before undergoing REM sleep. Slow-wave sleep (stages 3 and 4) occurs more frequently in the first half of the night, and REM sleep propensity is greater in the second half of the night.

A recent review concluded that there is evidence that aircraft noise can cause disrupted sleep as evidenced by increased number and length of awakenings, reduced slow-wave sleep and REM sleep, increased heart rate and blood pressure, as well as effects on subjective sleep quality and increased noise annoyance but with only a small effect on task performance the next day (Hales Swift, 2010). These conclusions mirror those of an earlier synthesis of field studies which concluded that there was sufficient evidence that nocturnal noise exposure (defined as rail, road, and aircraft noise) was causing direct biological responses, at approximately 40dB SEL, as well as affecting well-being and quality of sleep (HCN, 2004). This report also found that evidence was weaker for an effect of nocturnal noise on social interaction, task performance, and on specific disease symptoms. Recent evidence from the laboratory and field, confirms that nocturnal aircraft noise assessed as both average noise exposure during the night in the home (L_{Aeq}) and the number of noise events impairs cognitive performance the following morning, as evidenced by slower reaction times and lower accuracy on cognitive tasks (Elmenhorst *et al.*, 2010). These effects whilst small, were consistent and statistically significant, and could indicate an important public health implication of nocturnal aircraft noise exposure potentially influencing occupational performance.

In contrast to the reviews by Hales Swift (Hales Swift, 2010) and the Health Council for the Netherlands (HCN, 2004) a review focusing solely on aircraft noise exposure concluded that findings about noise-induced sleep disturbance differ considerably (Michaud *et al.*, 2007). The review, which was restricted to only five studies found little evidence for an effect of outdoor nocturnal aircraft noise on sleep disturbance, whilst indoor noise was associated more closely with sleep outcomes. There was evidence from these studies that a greater number of awakenings occur that are either spontaneous or attributable to other noise in the home, than are attributable to aircraft noise. The authors concluded that regulatory policy for night-time aircraft noise exposure should proceed cautiously, based on the findings of these five studies. However, sleep is a complex process and autonomic and minor sleep disruption does occur naturally during the sleep cycle in the absence of noise exposure (Hume, 2011a); conversely, autonomic responses to noise occurs at low levels that does not produce awakenings (Hume, 2011a, Muzet, 2007). Further, a large number of usually uncontrolled factors such as psychosocial stress, noise annoyance, age, physical and psychological health, and other individual differences affect both sleep and reaction to noise (Hume, 2011a). Michaud's conclusions are however supported by a laboratory study, which simulated the effect of aircraft noise exposure on sleep for 128 subjects over 13 nights (Basner and Samel, 2005). Prior to the experiment, the subjects spent a noise-free adaptation night in the laboratory, as sleep is initially affected by the laboratory setting. The experiment demonstrated a prominent first night exposure effect of noise on sleep disturbance, which wore off by the second night, which was interpreted as indicating habituation to noise exposure. On the subsequent nights no significant change in sleep structure was observed if the number of noise events and maximum sound pressure level did not exceed 4*80dB, 8*70dB, 16*60dB, 32*55dB, and 64*45dB. However, this study is still limited by having examined short-term exposure to aircraft noise, and conclusions cannot be drawn from these findings about the long-term effects of exposure to aircraft noise on sleep structure (Basner and Samel, 2005).

Studies have also suggested that environmental noise may impact differentially on different sleep stages, for example, aircraft noise induced sleep disturbance may be more likely to occur during later parts of the night, because there is less slow-wave sleep and sleep pressure is reduced (Michaud *et al.*, 2007). Conversely, it has been suggested that continuous noise exposure may be more likely to interrupt REM sleep, whilst intermittent noise may be more likely to interfere with slow-wave sleep (Passchier-Vermeer *et al.*, 2002). Further studies are required before firm conclusions can be drawn about the influence of nocturnal aircraft noise exposure on specific sleep stages.

An interesting recent laboratory study examined the potential effects of a change in the night-time curfew at Frankfurt airport on sleep disruption (Basner and Siebert, 2010). Using polysomnography on 128 subjects over 13 nights, three different operational scenarios were compared: scenario 1 was based on 2005 air traffic at Frankfurt airport which included night flights; scenario 2 was as scenario 1 but cancelled flights between 2300-0500 hours; scenario 3 was as scenario 1 but with flights between 2300-0500 hours rescheduled to the day-time and evening periods. The study found that compared to the night without a curfew on night flights (scenario 1), small improvements were observed in sleep structure for the nights with curfew, even when the flights were rescheduled to periods before and after the curfew period. The authors however conclude that the benefits for sleep seen in the scenario involving rescheduling of flights rather than cancellation may be offset by the expected increase in air traffic during the late evening and early morning hours for those who go to bed before 22.30 or after 01.00 hours. Whilst, this study has limited ecological validity, because of its laboratory setting it raises interesting possibilities regarding the setting of curfews for night-flights and the effects of different regulation regimes for night flights.

Evidence from field studies where change in nocturnal noise exposure has occurred also provides some evidence for an association between noise and sleep disturbance but the evidence is inconclusive. A Swedish study found that a reduction in road traffic noise exposure both during the day and during the night caused by a new road tunnel was associated with improvements in sleep quality and alertness, measured by actimetry and subjective reports (Öhrström, 2002). A large scale study of over 3500 subject-nights of observations, examining changes in night-time aircraft noise exposure at two airports in the United States found that noise change was not associated with changes in noise induced sleep disturbance (Fidell *et al.*, 2000). Overall, there are few studies examining changes in sleep disturbance, or other health outcomes, associated with either the reduction or increase in noise caused by a change in airport operations or through the installation of noise mitigation measures. Such studies remain a research priority.

One mechanism that has been suggested for the non-auditory effects of noise on human health, is that noise induced sleep disturbance could influence biological responses, which could have a long-term effect on health (HCN, 2004, Hume, 2011a). This potential mechanism for effects of nocturnal noise exposure on health has some support from studies linking sleep outcomes to later physical ill-health. A recent meta-analysis of longitudinal studies with at least a 3 year follow-up period, found that short duration of sleep, as assessed by questionnaire, predicted incident cases of coronary heart disease and stroke but not cardiovascular disease (Cappuccio *et al.*, 2011). Risk of developing or dying from coronary heart disease and stroke was increased by 48% and 15%, respectively for having ≤5-6 hours sleep per night compared with 7-8 hours sleep per night. However, sleep disturbance in these studies was not specifically related to noise and could have been a consequence of pre-existing ill-health.

Very few studies have included children and the specific effects of nocturnal aircraft noise on children's sleep are not known. One study used sleep logs and actigraphy to compare the effect of road traffic noise on child and parent sleep, finding an exposure-effect relationship between road traffic noise exposure and sleep quality and daytime sleepiness for children, and an exposure effect association between road traffic noise and sleep quality, awakenings, and perceived interference from noise for the parents (Öhrström *et al.*, 2006). Children are thought to have a higher awakening threshold than adults, so may be less vulnerable to noise effects on sleep (WHO, 2009); however, they are also likely to sleep earlier in the evening when aircraft noise exposure may be high. This field of research clearly warrants attention given the lack of knowledge available at present.

Taken as a whole, there are many laboratory and field studies which provide sufficient evidence that aircraft noise disturbs sleep and, depending on traffic volume and noise levels, may impair behaviour and well-being during the day (Basner *et al.*, 2010). However, the majority of evidence for the effect of aircraft noise on sleep disruption in community studies comes from cross-sectional studies (Basner *et al.*, 2010, Hume, 2011b), which do not enable the mechanisms for effects nor the role of long-term effects of aircraft noise disturbed sleep on health to be understood (Basner *et al.*, 2010). Further, little is known about the potential role of habituation to aircraft noise in relation to sleep disturbance. Evidence about these aspects could be obtained from large scale, longitudinal, epidemiological field studies, which include laboratory sub-studies (Basner *et al.*, 2010, Hume, 2011b, Jones, 2009). Such studies remain a research priority to further inform policy about the effects of nocturnal aircraft noise exposure on sleep disruption (Basner *et al.*, 2010, Hume, 2011b, Jones, 2009). Such studies should include repeated PSG assessment over a long-period of noise exposure, the assessment of health outcomes over a long-period, hormonal and cardiovascular measures to assess potential mechanisms for long-term effects of sleep disruption on health, and assessment of potential effect modifiers such as existing chronic ill-health (Basner *et al.*, 2010, Hume, 2011b, Jones, 2009). However, despite the existing gaps in knowledge on long-term health effects, experts believe that sufficient data are available for defining limit values, guidelines and protection, which should be updated with the availability of new data (Basner *et al.*, 2010).

One attempt to define such limits is the recent World Health Organisation Europe 'Night Noise Guidelines' (NNG) (WHO, 2009). These guidelines are the result of deliberations of international experts, which aim to provide clear guidance for planners and policy makers within Europe. The NNG use the noise metrics of $L_{night,\ outside}$, as used by the Environmental Noise Directive (END), the index of continuous sound levels outside during the night period (22.00-06.00 or 23.00-07.00), to define threshold levels for nocturnal noise exposure to protect health. The working group agreed that there was sufficient evidence that nocturnal noise exposure was related to self-reported sleep disturbance, medication use, and self-reported health problems and that there was some evidence along with biological plausibility for effects of nocturnal noise exposure on hypertension, myocardial infarction, and depression. This distinction reflects the relative newness of the L_{night} metric within the research field at the time the working group was convened. The NNG state that the target for nocturnal noise exposure should be 40 dB $L_{night,\ outside}$, which should protect the public as well as vulnerable groups such as the elderly, children, and the chronically ill from the effects of nocturnal noise exposure on health. The NNG also recommend the level of 55 dB $L_{night,\ outside}$, as an interim target for countries wishing to adopt a step-wise approach to the guidelines. An attempt to quantify the impact of nocturnal environmental noise exposure by the WHO Europe estimated that a total of 903 000 DALYs (Disability Adjusted Life Years) are lost per annum from noise-induced sleep disturbance for the EU population living in towns of >50 000 inhabitants (WHO, 2011).

3.3. Stress Hormones

Adrenaline, noradrenaline and cortisol, all of which are released by the adrenal glands in situations of stress have also been examined in relation to chronic aircraft noise exposure but these studies have demonstrated conflicting results (Babisch, 2003). These hormones can be extremely difficult to study as salivary and urinary measures of these hormones are easily biased by unmeasured factors. Cortisol has diurnal variation and is usually high in the morning and low in the evening making it difficult to measure effectively. Existing studies are further limited by small sample sizes.

A sub-study of the HYENA study, examined whether aircraft noise exposure was associated with salivary cortisol levels (Selander *et al.*, 2009). The sub-study found that aircraft noise exposure (L_{Aeq24}, L_{Aeq16}, L_{den}, $L_{evening}$, L_{night}) was associated with a significant increase in morning cortisol levels in women. Women exposed to >60dB L_{Aeq24} had a 34% higher morning saliva cortisol concentration compared with women exposed to <50dB L_{Aeq24} (Selander *et al.*, 2009). No effect was found for males, which may indicate that women are particularly susceptible to effects of aircraft noise on cortisol. Analyses by country, suggested that the association was stronger for the UK sample than for the samples from the other 5 countries. Interestingly, aircraft noise annoyance was not related to morning cortisol levels suggesting that the effect was not dependent on noise annoyance responses but was more directly associated with noise exposure.

Studies of aircraft noise exposure effects on endocrine markers in children have focused on day-time aircraft noise exposure at school. These studies, examining children living near London Heathrow airport found no association between aircraft noise exposure above 66 dB L_{Aeq16} and morning salivary cortisol measures (Haines *et al.*, 2001b), nor, in a similar study, between aircraft noise exposure above 62 dB L_{Aeq16}

and twelve-hour urinary cortisol, adrenaline and noradrenaline measures (Haines *et al.*, 2001a). However, the lack of associations could be explained by misclassification bias, as morning salivary cortisol may be more strongly influenced by nocturnal aircraft noise exposure at home rather than day-time aircraft noise exposure at school. However, it is likely that home and school aircraft noise exposure are highly correlated (Clark *et al.*, 2006, Haines *et al.*, 2001a). Also, for adults, the HYENA study found an effect on morning cortisol using both day and night-time aircraft noise metrics.

The evidence from the methodologically robust HYENA study provides some of the most compelling evidence for aircraft noise effects on adult endocrine responses seen to date. Previous evidence, mostly from studies of road traffic noise exposure was inconclusive and contradictory (Babisch, 2003). Further studies on the effects of nocturnal aircraft noise exposure on endocrine responses in children and adults are required. Little is known about whether raised endocrine responses observed in some studies represent normal short-term responses to environmental stress or a longer-term activation of the endocrine system. There is a lack of understanding about how long-term activation of the endocrine system links to health impairment and whether endocrine responses to noise exposure can habituate is not certain.

3.4. Annoyance

Annoyance is a multifaceted psychological concept including both evaluative and behavioural components (Guski, Schuemer, & Felscher-Shur, 1999), used to describe negative reactions to noise such as disturbance, dissatisfaction, displeasure, irritation, and nuisance (Guski *et al.*, 1999, Ouis, 2002). Annoyance is the most widespread, subjective response to noise (Cohen and Weinstein, 1981). The amount of the annoyance response explained by the sound level is generally thought to be small to moderate (Kroesen *et al.*, 2008, Le Masurier *et al.*, 2007, van Kempen and van Kamp, 2005). Acoustic factors such as noise source, exposure level and time of day of exposure only partly determine an individual's annoyance response: many non-acoustical factors such as the extent of interference experienced, ability to cope, expectations, fear associated with the noise source, noise sensitivity, anger, and beliefs about whether noise could be reduced by those responsible influence annoyance responses (WHO, 2000).

Noise annoyance is typically measured using the ISO question (ISO/TS 15666:2003) "Thinking about the last 12 months or so, when you were at home, how much does noise from aircraft bother disturb or annoy you?" answered either on a 5 point scale (Not at all, Slightly, Moderately, Very, Extremely) or on an 11 point numerical scale. Studies have derived exposure-effect associations for the effects of different noise sources on annoyance responses (Miedema and Oudshoorn, 2001, Schultz, 1978), finding that aircraft noise produces greater annoyance responses than road traffic noise at the same level of exposure (Miedema and

Vos, 1998, Miedema and Oudshoorn, 2001). The 'Miedema curves' (Miedema and Oudshoorn, 2001) are used with the European Union to predict the number of highly annoyed subjects (European Commission Working Group on Dose-Effect Relations, 2002). Table 1 is taken from the European Commission Working Group on Dose-Effect Relations, 2002 report (page 4), showing the % of the population annoyed and highly annoyed (Figure 2) by aircraft noise, road traffic noise, and rail noise. Unfortunately, these data use L_{den}, so look at noise exposure over the 24 hour period rather than for the night-time period per se. It is also important to realise that at any given sound level, a range of annoyance will be reported, as annoyance is not determined solely by sound level (Le Masurier *et al.*, 2007).

Table 1: % annoyed and % highly annoyed at various noise exposure levels (L_{den}) for aircraft, road traffic, and rail traffic (taken from the European Commission Working Group on Dose-Effect Relations, 2002, page 4).

Lden	Aircraft		Road traffic		Rail traffic	
	%A	%HA	%A	%HA	%A	%HA
45	11	1	6	1	3	0
50	19	5	11	4	5	1
55	28	10	18	6	10	2
60	38	17	26	10	15	5
65	48	26	35	16	23	9
70	60	37	47	25	34	14
75	73	49	61	37	47	23

Recent studies propose that the Miedema curves underestimate aircraft noise annoyance, suggesting that aircraft noise annoyance around major airports in Europe may have increased in recent years (Babisch *et al.*, 2009, Schreckenberg *et al.*, 2011). The HYENA study was able to compare annoyance responses separately for the day and the night period (Babisch *et al.*, 2009), finding that the London Heathrow sample reported significantly more annoyance to nocturnal aircraft noise than the samples from Schiphol Amsterdam, Tegel Berlin, Arlanda Stockholm, Bromma Stockholm, Malpensa Milan, and Elephterios Venizelos, Athens.

All the airports except Bromma Stockholm and Tegel Berlin allow night-flights, although some restrictions are in place (Jarup *et al.*, 2008). The authors argue that the difference between the airports in the presence of night-flights is unlikely to explain the higher annoyance observed around London Heathrow, however it remains possible that there may be differences between the airports in the number of night-flights or type of aircraft that may explain the higher annoyance observed. However, as previously noted, Schiphol Amsterdam and Elephterios Venizelos, Athens airports have a slightly higher number of night-flights compared with London Heathrow (EUROCONTROL, 2009). The London Heathrow sample also reported more day-time aircraft noise annoyance than the Schiphol Amsterdam, Tegel Berlin, Arlanda Stockholm, Bromma Stockholm, and Malpensa Milan samples. Whilst these data suggest that the population around

Heathrow are highly annoyed by both day-time and nocturnal aircraft noise, it must be remembered that the HYENA study examined a limited age range of 45-70 year old residents, and may therefore not be wholly representative of the population living around these airports.

The recent ANASE study (Attitudes to Noise from Aviation Sources in England) (Le Masurier *et al.*, 2007) carried out around 16 airports in England, found evidence that aircraft noise annoyance has increased over the past few decades in the UK, which could indicate that people have become less tolerant of environmental intrusion, and may have become less accepting of aircraft noise (Le Masurier *et al.*, 2007). Other studies have also indicated a trend for increased aircraft noise annoyance (Janssen *et al.*, 2011). The table below is taken from Le Masurier et al, 2007 (page 7.9) and indicates the range of annoyance scores in different L_{Aeq16} bands for residents around Heathrow airport, indicating fairly high levels of annoyance. In fact, mean annoyance levels around Heathrow airport were higher than the mean annoyance levels observed at other airports in England for a given L_{Aeq16}.

This survey used L_{Aeq16} noise metrics and it is therefore not possible to draw specific conclusions about the effects of nocturnal aircraft noise exposure on annoyance responses from this study. However, the ANASE study also examined willingness to pay to remove aircraft noise, with the findings suggesting that people are more sensitive to noise at night, particularly noise around midnight and the early hours.

Table 2: range of % annoyance scores by LAeq16 bands for Heathrow airport (taken from Le Masurier et al, 2007, page 7.9)

LAeq Band	No of Sites	Annoyance Range
37-41	1	19
41-45	2	17-25
45-49	6	22-42
49-53	7	29-50
53-57	4	42-64
57-61	5	59-74
61-65	2	64-76

It has also been suggested that noise annoyance responses might be an intermediate step between noise exposure and ill-health, although this hypothesis is not well supported by evidence. It has been suggested that noise annoyance may induce a stress reaction which could activate the sympathetic and endocrine systems leading to physiological changes such as changes in heart rate, blood pressure, and stress hormones (Babisch, 2011). Thus, noise annoyance could be an intervening step between noise and cardiovascular illnesses such as hypertension, as well as psychological symptoms such as depression. However, evidence for noise annoyance as a possible mediating factor between noise exposure and cardiovascular outcomes is mixed and largely comes from studies of road traffic annoyance (Babisch *et al.*, 2003, Belojevic and Saric-Tanaskovic, 2002). Evidence for annoyance as a mediating factor between noise exposure and psychiatric disorder is also weak, and it has been suggested that psychiatric disorder leads to annoyance rather than vice versa (Tarnopolsky *et al.*, 1978). It is likely that people with existing psychiatric morbidity or long term physical illness may be more disturbed and annoyed by noise and potentially more sensitive to any noise-related effects.

Recent studies have examined whether noise annoyance might moderate the effect of noise exposure on health outcomes. The HYENA study found that night-time aircraft noise annoyance was associated with use of anxiolytics and anti-hypertensive medication, but aircraft noise annoyance did not moderate the effect observed between nocturnal aircraft noise exposure and anxiolytic medication (Floud *et al.*, 2011). Similarly, the HYENA cortisol sub-study found that nocturnal aircraft noise annoyance did not relate to morning cortisol levels: women exposed to aircraft noise above >60 dB $L_{Aeq\ 24}$ hours had an increase in morning cortisol level regardless of whether or not they were annoyed by nocturnal aircraft noise (Selander *et al.*, 2009). Overall, further longitudinal studies of noise annoyance as a potential moderating or mediating factor of the effect of nocturnal aircraft noise exposure on health are required before more definite conclusions can be drawn.

Overall there is consistent evidence that aircraft noise annoyance has increased in recent years. In terms of London Heathrow airport specifically, there is evidence from methodologically strong studies that day-time aircraft noise annoyance is higher than that observed around other English airports, as well as evidence that nocturnal aircraft noise annoyance is higher than that observed around other European airports. Taken as a whole, this suggest that the population around London Heathrow may be especially vulnerable to annoyance responses, which would have implications if aircraft noise exposure were to increase due to changes in airport operations.

3.5. Cognitive Development

It has been suggested that children may be especially vulnerable to effects of environmental noise as they may have less cognitive capacity to understand and anticipate environmental stressors, as well as a lack of developed coping repertoires (Stansfeld *et al.*, 2000). Exposure to stressors during critical periods of learning at school could potentially impair development and have a lifelong effect on educational attainment (Kuh and Ben-Shlomo, 2004).

Overall, evidence for the effects of noise on children's cognition has strengthened in recent years (Evans and Hygge, 2007). One of the most interesting and compelling studies in this field is the naturally occurring longitudinal quasi-experiment reported by Evans and colleagues, examining the effect of the relocation of Munich airport on children's health and cognition (Evans *et al.*, 1998, Evans *et al.*, 1995, Hygge *et al.*, 2002). In 1992 the old Munich airport closed and was relocated. Prior to relocation, high noise exposure was associated with deficits in long term memory and reading comprehension. Two years after the closure of the airport, these deficits disappeared, indicating that noise effects on cognition may be reversible if exposure to the noise ceases. Most convincing, was the finding that deficits in memory and reading comprehension developed over the two year follow-up for children who became newly noise exposed near the new airport.

The largest study of noise effects on children's cognition and health to date, the RANCH study (Road and Aircraft Noise exposure and children's Cognition and Health), compared the effect of road traffic and aircraft noise exposure for over 2000 children attending schools around Schiphol Amsterdam, Barajas Madrid, and London Heathrow airports. The study found an exposure-effect relationship between chronic aircraft noise exposure (L_{Aeq16}) and impaired reading comprehension and recognition memory, after taking a range of socioeconomic and confounding factors into account (Stansfeld *et al.*, 2005). Aircraft noise was not associated with sustained attention or working memory. In terms of the magnitude of the effect of aircraft noise on reading comprehension, a 5dB L_{Aeq16} increase in aircraft noise exposure at school was associated with a 2 month delay in reading age in the UK and a 1 month delay in the Netherlands (Clark *et al.*, 2006): this association remained after adjustment for aircraft noise annoyance and cognitive abilities including episodic memory, working memory and attention.

The findings of the RANCH & Munich studies, along with previous findings (Haines *et al.*, 2001a, Hygge *et al.*, 2002) suggest that noise may directly affect reading comprehension and memory but they could be accounted for by other mechanisms including teacher and pupil frustration (Evans and Lepore, 1993), learned helplessness (Evans and Stecker, 2004) and impaired attention (Cohen *et al.*, 1973, Evans and Lepore, 1993). It has been suggested that children may adapt to chronic noise exposure by filtering or tuning out the unwanted noise stimuli: this filter may then be applied indiscriminately to situations where noise is not present, leading to learning deficits through lack of attention (Cohen *et al.*, 1986). The RANCH study concluded that whilst aircraft noise has only a small effect on reading comprehension, it is possible that children may be exposed to aircraft noise for many of their childhood years and the consequences of long-term noise exposure on cognitive development remain unknown (Clark *et al.*, 2006).

Studies of aircraft noise effects on children's cognition have predominantly focused on day-time noise exposure, estimated for either the child's school or home address. Few studies have focused specifically on nocturnal aircraft noise exposure in children. However, aircraft noise exposure outside school hours in the night, as well as in the evening may also impact on children's cognition: evening noise exposure could impact on children's learning activities carried out within the home, and evening and nocturnal exposure may also disturb sleep causing after effects on children's school performance during the day (Stansfeld *et al.*, 2010). Recent secondary analyses of the Munich and RANCH study datasets have examined the effects of nocturnal aircraft noise exposure at the child's home on cognition (Stansfeld *et al.*, 2010). Analyses of the Munich data revealed that self-reported sleep quality did not influence the associations observed between aircraft noise exposure and children's reading and memory, suggesting that sleep loss did not explain the effect of aircraft noise on cognition. Analyses of the RANCH data revealed that nocturnal aircraft noise exposure at the child's home was associated with impaired reading comprehension and recognition memory. However, nocturnal aircraft noise exposure had no additional effect on these cognitive outcomes, once day-time aircraft noise exposure at school had been taken into account. Whilst studies in West London have consistently found very high correlations between children's day-time aircraft noise exposure at school and nocturnal aircraft noise exposure at home (Clark *et al.*, 2006, Haines *et al.*, 2001a), these findings suggest that the school should be the main focus for the protection of children against the effects of aircraft noise on school performance (Stansfeld *et al.*, 2010).

3.6. Psychological Morbidity & Well-Being

Given the effect of chronic noise exposure on annoyance responses, it has been hypothesised that chronic noise exposure could have a serious effect on psychological health, as noise can cause annoyance and prolonged annoyance could lead to poor psychological health (McLean and Tarnopolsky, 1977). The effect of noise on psychological health is complicated as studies have found that poorer psychological health is also associated with greater annoyance responses (Tarnopolsky *et al.*, 1978, van Kamp *et al.*, 2007) and greater noise sensitivity (Stansfeld *et al.*, 1985).

Studies of aircraft noise exposure and psychological health in adults and children have predominantly used day-time or 24 hour noise exposure metrics, making it hard to establish the effects of nocturnal aircraft noise exposure, per se. Psychological morbidity as an outcome has been measured in several ways. Historically, research in this field started out examining associations of aircraft noise exposure on psychiatric diagnoses that could be diagnosed by an interview with a psychiatrist or by screening questionnaires. Later studies have tended to move away from this approach, due to the lack of evidence that noise exposure may relate to clinically diagnosable psychiatric disorders, to focus instead on increases in the number of psychological symptoms reported, such as symptoms of anxiety and depression. Recent studies have broadened this approach to include the assessment of well-being and quality of life.

In the West London Survey (Tarnopolsky *et al.*, 1980) aircraft noise exposure measured by the noise and number index was examined in relation to psychiatric disorder in the community measured by the General Health Questionnaire (Goldberg *et al.*, 1970). Both the pilot study and the main study of over 5000 adults living in areas of West London exposed to aircraft noise found no association between noise exposure and the prevalence of psychiatric morbidity either for GHQ scores or for estimated numbers of psychiatric cases, using various indices of noise exposure (Tarnopolsky *et al.*, 1978, Tarnopolsky and Morton-Williams, 1980, Tarnopolsky *et al.*, 1980). There was however some evidence of an association between aircraft noise exposure and psychiatric morbidity for participants with 'higher education' and 'professional/managerial occupations' (Tarnopolsky *et al.*, 1978, Tarnopolsky and Morton-Williams, 1980, Tarnopolsky *et al.*, 1980). The authors concluded that "noise per se in the community at large, does not seem to be a frequent, severe, pathogenic factor in causing mental illness but it is associated with symptomatic response in selected subgroups of the population" (Tarnopolsky and Morton-Williams, 1980). It should be considered that this study, along with many others in the field, may have predominantly sampled 'noise survivors' as members of the population who are most susceptible to noise effects may have moved away or avoided living in the area. The study also examines total noise exposure and does not distinguish day-time exposure from night-time exposure.

A recent study in Sardinia compared psychiatric diagnoses measured using the Composite International Diagnostic Interview for 71 residents living close to Elmas airport with control subjects matched by gender, age and employment status from another area (Hardoy *et al.*, 2005). Those living near the airport had a higher frequency of diagnosis for 'generalised anxiety disorder' and 'anxiety disorder not otherwise specified', compared with the controls; no differences were observed in frequency of diagnosis for 'major depressive disorder' or 'depressive disorder not otherwise specified'. However, the findings of this study should be treated with caution. The study is underpowered to detect psychiatric diagnoses with only a few participants with noise exposure having any of the psychiatric diagnoses. More seriously, there is potential for exposure misclassification in this study, as aircraft noise exposure was assumed based on residence in a district around Elmas airport; similarly, the control group were assumed not to have exposure to any type of noise exposure. The findings of this study are interesting but need replication in a much larger, better controlled study.

Several studies from Japan have indicated effects of military aircraft noise on psychological symptoms.
Exposure to higher daily levels of military aircraft noise around the Kadena military airport in Japan was related in an exposure-effect association to 'depressiveness' and 'nervousness' measured by questionnaire, using the Todai Health Index, based on the Cornell Medical Index (Hiramatsu *et al.*, 1997). A further Japanese study of 5,963 inhabitants around two air bases in Okinawa, also found that those exposed to

noise levels of L_{dn} 70 or above had higher rates of 'mental instability' and 'depressiveness' (Hiramatsu *et al.*, 2000). However, these studies are also seriously compromised by having estimated aircraft noise exposure using exposure data in the late 1970s and assessing health in the mid- 1990s, nearly 20 years after the noise surveys, making exposure-misclassification an important potential bias as noise exposure is known to have reduced in some of these areas in the intervening time-period with the end of the Vietnam war. A smaller-scale study after the opening of Narita International airport in Japan, found that scores on the GHQ-28 were significantly associated with average aircraft noise exposure during the period from evening to night (1800-2300 hours): the study did not examine the night period (Miyakawa *et al.*, 2007).

Most studies of aircraft noise effects on psychological health are cross-sectional, assessing exposure and health outcomes concurrently making it difficult to distinguish cause from effect. One of the few longitudinal studies of aircraft noise exposure and psychological health was carried out recently around Schiphol airport in Amsterdam, finding no association between L_{den} and L_{night} aircraft noise exposure levels and mental health assessed using the GHQ12 either at baseline, or after the opening of a fifth runway (van Kamp *et al.*, 2007).

Evidence for an effect of aircraft noise on well-being is inconclusive. A study of residents living around Frankfurt airport which has night-flights, found that whilst day-time aircraft noise exposure ($L_{Aeq\ 16\ hours\ 6am-10pm}$) was associated with the SF-36 vitality and mental health scales, and the SF-12 mental health scale, nocturnal aircraft noise exposure ($L_{night\ 10-6pm}$) showed no associations with these outcomes (Schreckenberg *et al.*, 2011). Similarly, lower scores on the general mental health scale of the SF-36 were associated with DNL (day-night average sound level) aircraft noise exposure in a study of residents around Sydney airport (Black *et al.*, 2007). Whilst these results suggest that there may be an association between daytime aircraft noise exposure and well-being, it is possible that several potential confounding factors have not been taken into account in these studies. Further studies are needed on associations between nocturnal aircraft noise exposure and well-being before firmer conclusions can be drawn.

Several studies have examined associations between aircraft noise exposure and children's psychological health, although most of these studies do not specifically examine nocturnal aircraft noise exposure. (Poustka *et al.*, 1992) studied the psychiatric health of 1636 4-16 year-old children in two geographical regions that differed according to the noise made by jet fighters frequently exercising at low altitude. Associations with noise exposure were demonstrated for subclinical depression and anxiety although there was no adjustment for the differing socioeconomic status of the areas. In a study that did adjust for socio-economic factors, the Schools Health & Environment Study around Heathrow airport (Haines *et al.*, 2001b), chronic aircraft noise exposure was not associated with anxiety and depression (measured with the Child Depression Inventory and the Taylor Manifest Anxiety Scale), after adjustment for socio-economic factors.

The larger West London School study of children attending school near London Heathrow airport found that aircraft noise exposed children had higher levels of psychological distress (Haines *et al.*, 2001a), as well as a higher prevalence of hyperactivity. The RANCH study failed to replicate an effect of aircraft noise exposure at school on psychological distress in samples from the Netherlands, Spain or the UK (Stansfeld *et al.*, 2005): however, the effect of aircraft noise on hyperactivity was replicated (Stansfeld *et al.*, 2009). Recent analyses of specific effects of nocturnal aircraft noise exposure showed no effects of nocturnal aircraft noise exposure on children's psychological distress (Stansfeld *et al.*, 2010).

Studies have also shown effects of noise exposure on milder indicators of children's psychological health. For example, in the Munich Study, children living in areas exposed to high aircraft noise had lower levels of psychological well-being than children living in quieter environments (Evans and Maxwell, 1997). In subsequent longitudinal analyses from around Munich, after the opening of the new airport, the newly noise-exposed communities demonstrated a significant decline in self-reported quality of life, measured on the Kindl scale, after being exposed to the increased aircraft noise for 18 months, compared with a control sample (Evans *et al.*, 1998). This longitudinal evidence is compelling.

Overall, the evidence suggests that for both adults and children aircraft noise exposure is probably not associated with serious psychiatric disorder, but that there may be effects on psychological symptoms, well-being, and quality of life. However, this conclusion is largely drawn from studies of day-time aircraft noise exposure and evidence in relation to nocturnal aircraft noise exposure is lacking. There may be a stronger link to psychiatric disorder for nocturnal noise exposure and further studies need to explore this issue in large scale longitudinal studies using standardised interview measures of psychiatric disorder.

4 CONCLUSION

In conclusion, this review indicates that nocturnal aircraft noise exposure is potentially associated with considerable public health impact and impact on quality of life for residents living near major airports. Whilst gaps in knowledge remain regarding effects of nocturnal aircraft noise exposure on psychological health and well-being, and for longer-term health outcomes, evidence for an effect of nocturnal aircraft noise exposure on human health has strengthened over the past decade. There is good and robust evidence for an effect of nocturnal aircraft noise exposure on hypertension, sleep disturbance, and noise annoyance. This evidence is sufficient to support preventive measures such as policy, guidelines, and limit values for nocturnal aircraft noise exposure in communities near airports. The need for a preventive approach is further strengthened by the evidence from several recent studies which indicate that the population around Heathrow airport may be particularly vulnerable to effects of nocturnal aircraft noise on health. There is a need to consider the protection of public health and quality of life in the surrounding area when considering night flying regimes around London Heathrow airport.

5 REFERENCES

Babisch, W. (2003). Stress hormones in the research on cardiovascular effects of noise. *Noise Health* **5**, 1-11.

Babisch, W. (2005). Noise and health. *Environmental Health Perspectives* **113**, A14-A15.

Babisch, W. (2006). Transportation noise and cardiovascular risk: updated review and synthesis of epidemiological studies indicate that the evidence has increased. *Noise and Health* **8**, 1-29.

Babisch, W. (2011). Cardiovascular effects of noise. *Noise & Health* **13**, 201-204.

Babisch, W., Houthuijs, D., Pershagen, G., Cadum, E., Katsouyanni, K., Velonakis, M., Dudley, M. L., Marohn, H. D., Swart, W., Breugelmans, O., Bluhm, G., Selander, J., Vigna-Taglianti, F., Pisani, S., Haralabidis, A., Dimakopoulou, K., Zachos, I. & Järup, L. (2009). Annoyance due to aircraft noise has increased over the years--results of the HYENA study. *Environment International* **35**, 1169-1176.

Babisch, W., Ising, H. & Gallacher, J. E. J. (2003). Health status as a potential effect modifier of the relation between noise annoyance and incidence of ischaemic heart disease. *Occupational and Environmental Medicine* **60**, 739-745.

Basner, M., Griefahn, B. & Berg, M. (2010). Aircraft noise effects on sleep: mechanisms, mitigation and research needs. *Noise and Health* **12**, 95-109.

Basner, M., Müller, U. & Elmenhorst, E. M. (2011). Single and combined effects of air, road, and rail traffic noise on sleep and recuperation. *Sleep* **34**, 11-23.

Basner, M. & Samel, A. (2005). Effects of nocturnal aircraft noise on sleep structure *Somnologie* **9**, 84-95.

Basner, M. & Siebert, U. (2010). Markov processes for the prediction of aircraft noise effects on sleep. *Medical Decision Making* **30**, 275-89.

Belojevic, G. & Saric-Tanaskovic, M. (2002). Prevalence of arterial hypertension and myocardial infarction in relation to subjective ratings of traffic noise exposure. *Noise & Health* **4**, 33-37.

Black, D. A., Black, J. A., Issarayangyun, T. & Samuels, S. E. (2007). Aircraft noise exposure and resident's stress and hypertension: a public health perspective for airport environmental management. *Journal of Air Transport Management* **13**, 264-276.

Cappuccio, F. P., Cooper, D., D'Elia, L., Strazzullo, P. & Miller, M. A. (2011). Sleep duration predicts cardiovascular outcomes: a systematic review and meta-analysis of prospective studies. *European Heart Journal* **32**, 1484-92.

Clark, C., Martin, R., van Kempen, E., Alfred, T., Head, J., Davies, H. W., Haines, M. M., Barrio, I. L., Matheson, M. & Stansfeld, S. A. (2006). Exposure-effect relations between aircraft and road traffic noise exposure at school and reading comprehension - The RANCH project. *American Journal of Epidemiology* **163**, 27-37.

Clark, C. & Stansfeld, S. A. (2007). The effect of transportation noise on health and cognitive development: a review of recent evidence. *International Journal of Comparative Psychology* **20**, 145-158.

Cohen, S., Evans, G. W., Stokols, D. & Krantz, D. S. (1986). *Behavior, Health and Environmental Stress* Plenum Press: New York.

Cohen, S., Glass, D. C. & Singer, J. E. (1973). Apartment noise, auditory discrimination, and reading ability in children. *Journal of Experimental Social Psychology* **9**, 407-422.

Cohen, S. & Weinstein, N. (1981). Non-auditory effects of noise on behaviour and health *Journal of Social Issues* **37**, 36-70.

Department for Transport (2011). Developing a sustainable framework for UK aviation: Scoping document. Department for Transport: London.

Directive 2002/49/EC (2002). Directive of the European Parliament and of the Council of 25 June 2002 relating to the assessment and management of environmental noise. Official Journal of the European Communities L 189:12-25; 2002.

Elmenhorst, E. M., Elmenhorst, D., Wenzel, J., Quehl, J., Mueller, U., Maass, H., Vejvoda, M. & Basner, M. (2010). Effects of nocturnal aircraft noise on cognitive performance in the following morning: dose-response relationships in laboratory and field. *International Archives of Occupational and Environmental Health* **83**, 743-51.

Eriksson, C., Rosenlund, M., Pershagen, G., Hilding, A., Östenson, C. & Bluhm, G. (2007). Aircraft noise and incidence of hypertension. . *Epidemiology* **18**, 716-721.

EUROCONTROL (2009). Trends in Air Traffic: Volume 5. Dependent on the dark: cargo and other night flights in European airspace. EUROCONTROL: Brussels.

European Commission Working Group on Dose-Effect Relations (2002). Position paper on dose response relations between transportation noise and annoyance. Office for Official Publications of the European Communities: Luxembourg.

Evans, G. & Lepore, S. (1993). Non-auditory effects of noise on children: a critical review. *Children's Environments* **10**, 42-72.

Evans, G. W., Bullinger, M. & Hygge, S. (1998). Chronic noise exposure and physiological response: A prospective study of children living under environmental stress. *Psychological Science* **9**, 75-77.

Evans, G. W. & Hygge, S. (2007). Noise and performance in children and adults. In *Noise and its effects* (ed. L. Luxon and D. Prasher). Whurr Publishers: London.

Evans, G. W., Hygge, S. & Bullinger, M. (1995). Chronic noise and psychological stress. *Psychological Science* **6**, 333-338.

Evans, G. W. & Maxwell, L. (1997). Chronic noise exposure and reading deficits: The mediating effects of language acquisition. *Environment and Behavior* **29**, 638-656.

Evans, G. W. & Stecker, R. (2004). Motivational consequences of environmental stress. *Journal of Environmental Psychology* **24**, 143-165.

Fidell, S., Pearsons, K., Tabachnick, B. G. & Howe, R. (2000). Effects of sleep disturbance of changes in aircraft noise near three airports. *Journal of the Acoustic Society of America* **107**, 2535-47.

Floud, S., Vigna-Taglianti, F., Hansell, A., Blangiardo, M., Houthuijs, D., Breugelmans, O., Cadum, E., Babisch, W., Selander, J., Pershagen, G., Antoniotti, M. C., Pisani, S., Dimakopoulou, K., Haralabidis, A. S., Velonakis, V., Jarup, L. & Team., H. S. (2011). Medication use in relation to noise from aircraft and road traffic in six European countries: results of the HYENA study. *Occupational and Environmental Medicine* **68**, 518-24.

Goldberg, D. P., Cooper, B., Eastwood, M. R., Kedward, H. B. & Shepherd, M. (1970). A standardized psychiatric interview for use in community surveys. *British Journal of Preventive and Social Medicine* **24**, 18-23.

Greiser, E., Greiser, C. & Janhsen, K. (2007). Night-time aircraft noise increases prevalence of prescriptions of antihypertensive and cardiovascular drugs irrespective of social class – the Cologne-Bonn airport study. *Journal of Public Health* **15**.

Guski, R., Schuemer, R. & Felscher-Shur, U. (1999). The concept of noise annoyance: how international experts see it. *Journal of Sound and Vibration* **223**, 513-527.

Haines, M. M., Stansfeld, S. A., Brentnall, S., Head, J., Berry, B., Jiggins, M. & Hygge, S. (2001a). The West London Schools Study: the effects of chronic aircraft noise exposure on child health. *Psychological Medicine* **31**, 1385-1396.

Haines, M. M., Stansfeld, S. A., Job, R. F., Berglund, B. & Head, J. (2001b). Chronic aircraft noise exposure, stress responses, mental health and cognitive performance in school children. *Psychological Medicine* **31**, 265-277.

Hales Swift (2010). Partner Project 19: A review of the literature related to potential health effects of aircraft noise. Report No. COE-2010-003.

Hardoy, M. C., Carta, M. G., Marci, A. R., Carbone, F., Cadeddu, M., Kovess, V., Dell'Osso, L. & Carpiniello, B. (2005). Exposure to aircraft noise and risk of psychiatric disorders: the Elmas survey--aircraft noise and psychiatric disorders. *Social Psychiatry and Psychiatric Epidemiology* **40**, 24-6.

HCN (2004). The influence of night-time noise on sleep and health (2004/14E). Health Council of the Netherlands: The Hague.

Hiramatsu, K., Minoura, T., Matsui, T., Miyakita, T., Osada, Y. & Yamamoto, T. (2000). An analysis of the general health questionnaire survey around airports in terms of annoyance reaction. In *Internoise 2000*: Nice, France.

Hiramatsu, K., Yamamoto, T., Taira, K., Ito, A. & Nakasone, T. (1997). A survey on health effects due to aircraft noise on residents living around Kadena airport in the Ryukyus *Journal of Sound and Vibration* **205**, 451-460.

Hume, K. (2011a). Overview of research into sleep disturbance due to noise in the last three years. In *International Commission on the Biological Effects of Noise*: London.

Hume, K. I. (2011b). Noise pollution: a ubiquitous unrecognized disruptor of sleep? *Sleep* **34**, 7-8.

Huss, A., Spoerri, A., Egger, M. & Röösli, M. (2010). Aircraft noise, air pollution, and mortality from myocardial infarction. *Epidemiology* **21**, 829-36.

Hygge, S., Evans, G. W. & Bullinger, M. (2002). A prospective study of some effects of aircraft noise on cognitive performance in schoolchildren. *Psychological Science* **13**, 469-74.

ISO/TS 15666:2003 Assessment of noise annoyance by means of social and socio-acoustic surveys. Geneva.

Janssen, S. A., Vos, H., van Kempen, E. E., Breugelmans, O. R. & Miedema, H. M. (2011). Trends in aircraft noise annoyance: the role of study and sample characteristics. *Journal of Acoustical Society of America* **129**, 1953-62.

Jarup, L., Babisch, W., Houthuijs, D., Pershagen, G., Katsouyanni, K., Cadum, E., Dudley, M. L., Savigny, P., Seiffert, I., Swart, W., Breugelmans, O., Bluhm, G., Selander, J., Haralabidis, A., Dimakopoujou, K., Sourtzi, P., Velonakis, M., Vigna-Taglianti, F. & Team, H. S. (2008). Hypertension and exposure to noise near airports: the HYENA study. *Environmental Health Perspectives* **116**, 329-333.

Jones, K. (2009). Aircraft noise and sleep disturbance: a review. ERCD Report 0905.

Kroesen, M., Moline, E. J. E. & van Wee, B. (2008). Testing a theory of aircraft noise annoyance: a structural equation analysis. *Journal of Acoustical Society of America* **123**, 4250-60.

Kryter, K. D. (1985). *The Effects of Noise on Man*. Academic Press: Orlando, FL.

Kuh, D. & Ben-Shlomo, Y. (2004). *A Lifecourse Approach to Chronic Disease Epidemiology*. Oxford University Press: Oxford.

Le Masurier, P., Bates, J., Taylor, J., Flindell, I., Humpheson, D., Pownall, C. & Woolley, A. (2007). Attitudes to Noise from Aviation Sources in England. Queen's printer and Controller of HMSO: Norwich.

McLean, E. K. & Tarnopolsky, A. (1977). Noise, discomfort and mental health. A review of the socio-medical implications of disturbance by noise. *Psychological Medicine* **7**, 19-62.

Michaud, D. S., Fidell, S., Pearsons, K., Campbell, K. C. & Keith, S. E. (2007). Review of field studies of aircraft noise-induced sleep disturbance. *Journal of the Acoustical Society of America* **121**, 32-41.

Miedema, H. M. & Vos, H. (1998). Exposure-response relationships for transportation noise. *Journal of Acoustical Society of America* **104**, 3432-45.

Miedema, H. M. E. & Oudshoorn, C. G. (2001). Annoyance from transportation noise: relationships with exposure metrics DNL and DENL and their confidence intervals. *Environmental Health Perspectives* **109**, 409-416.

Miedema, H. M. E. & Vos, H. (2007). Associations between self-reported sleep disturbance and environmental aircraft noise-induced sleep disturbance. *Journal of the Acoustical Society of America* **121**, 32-41.

Miyakawa, M., Matsui, T. & Hiramatsu, K. (2007). Relationship between psychiatric disorder and disturbance of daily life due to aircraft noise exposure: epidemiological study around Narita International Airport. In *Internoise 2007*: Istanbul, Turkey.

Muzet, A. (2007). Environmental noise, sleep and health. *Sleep Medicine Reviews* **11**, 135-142.

Öhrström, E. (2002). Sleep studies before and after – results and comparison of different methods. Noise & Health, 4 (15), 65-67. . *Noise and Health* **4**, 65-67.

Öhrström, E., Hadzibajramovic, E., Holmes, M. & Svensson, H. (2006). Effects of road traffic noise on sleep: studies on children and adults. *Journal of Environmental Psychology* **26**, 116-126.

Ouis, D. (2002). Annoyance caused by exposure to road traffic noise: an update. *Noise & Health* **4**, 69-79.

Passchier-Vermeer, W., Vos, H., Steenbekkers, J., van der Ploeg, F. & Groothuis-Oudshoorn, K. (2002). Sleep disturbance and aircraft noise exposure: exposure-effect relationships TNO Report No. 2002.027. : Den Haag:the Netherlands.

Paunovic, K., Stansfeld, S., Clark, C. & Belojevic, G. (2011). Epidemiological studies on noise and blood pressure in children: Observations and suggestions. *Environment International* **37**, 1030-41.

Poustka, F., Eckermann, P. & Schmeck, K. (1992). Effect of aircraft noise and psychosocial stressors on mental disturbances of children and adolescents: an epidemiological study in Westphalia. . In *Developmental Psychopathology* (ed. H. Remschmidt and M. H. Schmidt). Hogrefe and Huber Publishers: Gottingen. Federal Republic of Germany.

Schreckenberg, D., Meis, M., Kahl, C., Peschel, C. & Eikmann, T. (2011). Aircraft noise and quality of life around Frankfurt Airport. *International Journal of Environmental Research and Public Health* **7**, 3382-405.

Schultz, T. J. (1978). Synthesis of social surveys on noise annoyance. *Journal of Acoustical Society of America* **64**, 377-406.

Selander, J., Bluhm, G., Theorell, T., Pershagen, G., Babisch, W., Seiffert, I., Houthuijs, D., Breugelmans, O., Vigna-Taglianti, F., Antoniotti, M. C., Velonakis, E., Davou, E., Dudley, M. L. & Järup, L. (2009). Saliva cortisol and exposure to aircraft noise in six European countries. *Environmental Health Perspectives* **117**, 1713-7.

Sørensen, M., Hvidberg, M., Andersen, Z. J., Nordsborg, R. B., Lillelund, K. G., Jakobsen, J., Tjønneland, A., Overvad, K. & Raaschou-Nielsen, O. (2011). Road traffic noise and stroke: a prospective cohort study. *European Heart Journal* **32**, 737-744.

Stansfeld, S., Clark, C., Cameron, R. M., Alfred, T., Head, J., Haines, M. M., van Kamp, I., van Kempen, E. & Lopez-Barrio, I. (2009). Aircraft and road traffic noise exposure and children's mental health. *Journal of Environmental Psychology* **29**, 203-207.

Stansfeld, S., Hygge, S., Clark, C. & Alfred, T. (2010). Night time aircraft noise exposure and children's cognitive performance. *Noise & Health* **12**, 255-262.

Stansfeld, S. A., Berglund, B., Clark, C., Lopez-Barrio, I., Fischer, P., Ohrstrom, E., Haines, M. M., Head, J., Hygge, S., van Kamp, I. & Berry, B. F. (2005). Aircraft and road traffic noise and children's cognition and health: a cross-national study. *Lancet* **365**, 1942-9.

Stansfeld, S. A., Clark, C. R., Turpin, G., Jenkins, L. M. & Tarnopolsky, A. (1985). Sensitivity to noise in a community sample: II. Measurement of psychophysiological indices. *Psychol Med* **15**, 255-63.

Stansfeld, S. A., Haines, M. M. & Brown, B. (2000). Noise and health in the urban environment. *Reviews of Environmental Health* **15**, 43-82.

Tarnopolsky, A., Barker, S. M., Wiggins, R. D. & McLean, E. K. (1978). The effect of aircraft noise on the mental health of a community sample: a pilot study. *Psychological Medicine* **8**, 219-33.

Tarnopolsky, A. & Morton-Williams, J. (1980). Aircraft Noise and Prevalence of Psychiatric Disorders. Social and Community Planning Research: London.

Tarnopolsky, A., Watkins, G. & Hand, D. J. (1980). Aircraft noise and mental health: I. Prevalence of individual symptoms. *Psychological Medicine* **10**, 683-98.

van Kamp, I., Houthuijs, D., van Wiechen, C. & Breugelmans, O. (2007). Environmental noise and mental health: evidence from the Schiphol monitoring program. In *Internoise 2007*: Istanbul, Turkey.

van Kempen, E., Kruize, H., Boshuizen, H. C., Ameling, C. B., Staatsen, B. A. M. & de Hollander, A. E. M. (2002). The association between noise exposure and blood pressure and ischemic heart disease: a meta analysis. *Environmental Health Perspectives* **110**, 307-317.

van Kempen, E. & van Kamp, I. (2005). Annoyance from air traffic noise. Possible trends in exposure-response relationship. Report 01/2005. RIVM: Bilthoven.

van Kempen, E., Van Kamp, I., Fischer, P., Davies, H., Houthuijs, D., Stellato, R., Clark, C. & Stansfeld, S. (2006). Noise exposure and children's blood pressure and heart rate: the RANCH project. *Occupational and Environmental Medicine* **63**, 632-639.

WHO (2000). *Guidelines for Community Noise*. World Health Organisation: Geneva.

WHO (2009). Night Noise Guidelines for Europe. World Health Organisation: Copenhagen.

WHO (2011). Burden of disease from environmental noise. World Health Organisation Europe: Copenhagen.