

Aircraft noise and health effects: Recent findings

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Chapter 1

Introduction

- 1.1 The report aims to provide an update to the Environmental and Research Consultancy Department Report 0907 entitled Environmental Noise and Health Effects. Published in 2009, that report examined the evidence to date relating to transportation noise, in particular aircraft noise and the resulting impacts on various health endpoints. These included cardiovascular disease, night-time effects on sleep disturbance, children's cognition, psychological effects, performance and annoyance.
- 1.2 Aircraft noise and health effects is a rapidly growing area of research worldwide, and there have been many important findings published in recent years. Of particular importance has been the European Network of Noise and Health (ENNAH), which has connected researchers in the field throughout Europe to critically assess the current evidence base and identify gaps in the knowledge as well as suggesting directions for future research. The World Health Organisation (WHO) published their Burden of Disease from Environmental Noise report, which has enabled the calculation of healthy life years lost due to environmental noise which is very important for decisions on policy making. The European Environment Agency published their good practice guide on noise exposure and potential health effects which included important exposure-response relationships and thresholds for health endpoints and the Health and Safety Laboratory, through a Defra contract, produced their work on quantifying the links between environmental noise related hypertension and health effects.
- 1.3 In 2015 a review of aircraft noise and health effects by Charlotte Clark was published alongside the Airports Commission's final report on increasing airport capacity in the UK. The review was focused on the current state of knowledge concerning the effects of aircraft noise on a range of health outcomes, and the subsequent potential effects on exposed populations for three different expansion options. The review concluded that there is increasing evidence to support preventive measures such as insulation, policy, guidelines and limit values. Priorities for minimising the effects of aircraft noise should be focused on reducing annoyance, improving school environments for children and aiming to lower cardiovascular risk factors.
- 1.4 In addition to these key publications there have been many more studies into aviation noise and health effects since 2009. This report will review the main findings between 2009 and 2015 and will highlight areas that are considered important for future research.

- 1.5 The scope of this paper will focus around the cardiovascular impacts, sleep disturbance and children's learning with other areas such as performance and psychological effects being included. Although annoyance is often considered a health effect, for the purpose of this paper it will not be included as a single end point health effect, but of course it is appreciated that annoyance may be an important mediator in the relationship between aircraft noise, stress and various health endpoints such as cardiovascular disease. A dedicated CAP report on the current knowledge on aircraft noise and annoyance is planned.

Chapter 2

Cardiovascular effects

- 2.1 A Swedish study (Eriksson et al 2010) examined the cumulative gender-specific effects of aircraft noise on hypertension in a population of over 4000 adults residing close to Stockholm Arlanda airport. The study followed the participants over a period of 8-10 years and in addition to the main aim of investigating any potential differences between genders, the study also looked at the presence of sensitive sub-groups within the cohort. The study was part of a larger study on diabetes Type 2 risk factors and prevention measures, and therefore half of the sample in the aircraft noise study had a family history of diabetes. Baseline health measurements were taken at the beginning of the study, such as weight, waist and hip circumference and blood pressure. Participants also answered an extensive questionnaire on lifestyle factors and treatment for hypertension if there was any. After 8-10 years a follow-up questionnaire was administered with the same questions as in the baseline study, only with additional questions pertaining to aircraft noise and annoyance, noise sensitivity and diagnosis of hypertension.
- 2.2 Participants who were taking medication for hypertension at baseline were excluded from the aircraft noise study at follow up, along with those people displaying high blood pressure and/or those with missing data. During the study period the introduction of quieter aircraft resulted in a continuous decrease of the noise levels overall around the airport and interestingly a third runway was also built. This changed the flight paths which meant that most people experienced a decrease in noise levels, but as expected some areas experienced the opposite. Aircraft noise levels ranging from 50-65 dBA L_{den} were provided by Swedish Airports and Air Navigation Services, and were estimated with 1 dB(A) resolution using the Integrated Noise Model (INM). Exposure assessment was performed by Geographical Information Systems (GIS) and based on residential history during the period of the follow-up.
- 2.3 The results suggested that men and women exposed to 50 dBA L_{den} or above had a lower socioeconomic status and were more likely to work shifts than those exposed to below 50 dBA L_{den} . Alcohol consumption was lower for both sexes in the higher noise group also. Age and body mass index was associated with hypertension in males and females. Annoyance was strongly related to noise exposure, with 80% of people expressing annoyance when exposed to aircraft noise of 60 dBA L_{den} or above. Interestingly, males were more annoyed from 50 dBA L_{den} or above than females (36% and 29% respectively).

- 2.4 The hypertension results indicated that males were more likely to develop hypertension in areas exposed to 50 dB(A) L_{den} or above than females. For men the Relative Risk (RR) was 1.02 (95% CI 0.92-1.29) compared to women having a RR of 0.92 (95% CI 0.76-1.11). This was not a statistically significant difference among genders and as an overall sample there was no increased risk of hypertension following long-term aircraft noise exposure. However, when the cohort was restricted to those people not smoking at the time of the blood pressure measurements, a significant increase in risk per 5 dB was found in males RR 1.21 (1.05–1.39) but not in females RR 0.97(0.83–1.13). The authors explain that this may be due to nicotine having short-term effects on blood pressure and can therefore possibly skew the measurements. When both sexes were combined there was an increased risk for aircraft-noise related hypertension among those people that had reported annoyance to aircraft noise RR 1.42(1.11–1.82).
- 2.5 The authors suggest that it is possible that subjects with perceived noise annoyance represent a subgroup that is under greater risk of developing hypertension related to noise exposure. A possible explanation is that if noise-related hypertension is mediated through annoyance, this could contribute to explaining the observed gender difference in this study since men were more prone than women to report aircraft noise annoyance (36% and 29%, respectively). Observed annoyance levels were higher than expected, and this may be due to the increased awareness of aircraft noise with the opening of the third runway during the study period. An important point to consider when interpreting the difference in hypertension risk between the sexes is that on average women tend to develop hypertension when they are about ten years older than men, and this may be a contributing factor to the results observed in this study. It is also possible that the differences found between sexes may be attributable to confounding factors that are not accounted for. Finally, the sample used had a higher percentage of family history of diabetes (50%) compared to the standard proportion of 20-25% in the general population of corresponding age group which may predispose some of the population to a higher risk of cardiovascular disease.
- 2.6 Greiser et al (2011) published research concerning the risk increase of cardiovascular diseases and impact of aircraft noise in the Cologne-Bonn airport study. Previously, research had shown that there was an increase in the amount of cardiac medication prescribed with increasing aircraft noise exposure (2007). Aircraft, road and rail noise data were linked to hospital discharge diagnoses of just over one million people living in the study area. Confounders included age, environmental noise, prevalence of social welfare recipients of residential quarters and interaction of aircraft noise with age. The results showed that as age increased, the risk of cardiovascular disease decreased. Risk is more marked in females than males. For night-time aircraft noise of 50 dB L_{night} at

aged 50, the odds ratio for cardiovascular disease in men was 1.22 and in women 1.54, for myocardial infarction it was 1.18 in men and 1.54 in women, for heart failure in men 1.52 and 1.59 in women, stroke in men 1.36 and for women 1.36 also. The lack of difference between males and females for heart failure risk and stroke contradicts the hypertension findings with respect to gender in the Swedish study, although this study uses the L_{night} metric rather than L_{den} , which may be a factor.

- 2.7 Floud et al (2011) reported on medication use in relation to aircraft noise of populations surrounding six European airports, as part of the HYENA study. Differences were found between countries in terms of the effect of aircraft noise on antihypertensive use. For night-time aircraft noise a 10 dB increase was associated with an odds ratio of 1.34 (95% CI 1.14 to 1.57) for the UK and 1.19 (CI 1.02 to 1.38) for the Netherlands but no significant associations were found for other countries. There was also an association between aircraft noise and anxiolytic (anti-anxiety) medication, OR 1.28 (CI 1.04 to 1.57) for daytime and OR 1.27 (CI 1.01 to 1.59) for night-time. It should be noted that these confidence intervals are considerable in variation. This effect was found across countries. The authors concluded that although results suggested a possible effect of aircraft noise on the use of antihypertensive medication, the effect did not hold for all countries. The data was more consistent for anxiolytics in relation to aircraft noise across countries.
- 2.8 Harding et al (2011) on behalf of the Health and Safety Laboratory published a report on the quantification of noise related hypertension and the related health effects. The aims of the study were to identify the potential health outcomes associated with hypertension, to prioritise the health outcomes and quantify the links between noise and selected hypertension associated health outcomes. The second half of the report covered a methodology to allow a monetary value to be placed on the links between hypertension and health outcomes.
- 2.9 The base dose-response function for noise and hypertension used by Harding comes from Babisch and van Kamp (2009) who found an odds ratio for hypertension of 1.13 per 10 dBA increase in L_{den} in the range 45 to 70 dBA. Harding goes on to note that because the prevalence of hypertension in the population is greater than ten percent, that the odds ratio must be converted into relative risk in order to quantify the effect on the population.
- 2.10 Previously, the Interdepartmental Group on Cost Benefit analysis of noise IGCB(N) and WHO have considered that there is insufficient certainty from which to quantify the health outcomes from hypertension. However, Harding et al, after in depth review, found the following health outcomes from hypertension could be quantified.
- 2.11 The report concluded that there is substantial evidence for hypertension and blood pressure being an independent risk for cardiovascular disease (CVD).

Many studies investigating hypertension or blood pressure as an independent causal factor for CVD have used separate analyses for stroke and Ischaemic Heart Disease (IHD). It has been suggested that systolic blood pressure may be a better indicator of CVD risk than diastolic blood pressure.

- 2.12 The report discusses evidence of blood pressure being linked to all types of stroke, ischaemic (resulting from a clot) and haemorrhagic (rupturing of blood vessels within the brain). Hypertension is a known risk factor for strokes. There is strong evidence for a link between blood pressure and the incidence and mortality of IHD. IHD is due to the build up of plaque deposits on the artery walls and therefore leads to hardening of the arteries. When the plaque comes away from the walls, blockages can occur in the arteries which can cause a lack of oxygen (ischaemia) in the heart muscle. When the rupture of plaque on the coronary arteries occurs a clot can form, which can subsequently cause a rapid slowing or stop of blood flow and then the classic heart attack (myocardial infarction). There is evidence that lowering blood pressure can help prevent heart attacks.
- 2.13 The report discusses the evidence linking hypertension and dementia, or cognitive decline. The evidence is less strong than for cardiovascular disease, and is complicated by the ethical issues involved in studying long-term hypertension without treatment and also because by the time dementia manifests, hypertension can decrease as a result of weight loss or metabolic changes. There have also been findings that link cognitive decline with blood pressure in subjects aged 59-71 years.
- 2.14 The report also discussed the links between hypertension and end stage kidney disease, pregnancy, eye conditions and sexual function, but it was decided that based on the strength of the evidence and impact on the population that three health outcomes would be given priority in terms of quantification of links between noise and hypertension. These were Acute Myocardial Infarction (AMI), stroke and dementia. It should be noted that this study was designed to assess the risk of noise-related hypertension on the subsequent likelihood of hypertension resulting in the above health outcomes; it is not reporting that noise itself directly causes stroke and dementia.
- 2.15 Paunović et al (2011) published a critical review of studies into road and aircraft noise and children's blood pressure. The aim of the review was to compare the methodologies used to assess blood pressure across the thirteen studies included. Of the seven studies on aircraft noise and children's blood pressure, three were cross-sectional; four were longitudinal with a follow-up of between one and three years. The children were of similar age, between 8-12 years old, with weight and height measured and controlled for in most of the studies as well as ethnicity and in most cases, family history of hypertension. Noise exposure did vary across the studies, with some measurements being taken at schools,

and some at residences. In terms of noise metrics, some studies used daytime levels; others used 24 hour noise levels, or monthly averaged exposure.

- 2.16 The measurement of blood pressure was fairly standard across the studies and used automatic measurement techniques, although there were discrepancies in terms of place, time and number of measurements taken and the degree of control for confounding factors. Despite these variations within the methodology, the authors conclude that there is a tendency toward positive association with noise exposure and an increase in children's blood pressure. It is recommended that more precise guidelines for measuring blood pressure in field studies are put in place. Some suggestions for such standardised protocols are summarised:
- Children's blood pressure should be measured at approximately the same time, either morning or afternoon.
 - The place where measurement occurs should be familiar, well lit, quiet and comfortable.
 - At least three measurements should be taken a few minutes apart, with the first reading being discarded.
 - Measurements should be repeated the following day in the same setting if possible.
 - Instructions should be given verbally and in written form.
 - Measurements should be taken after breakfast, intense physical activity, coffee or energy drinks, and psychoactive substances such as nicotine.
 - The child's emotions should be asked about and measurements avoided if there is expression of anxiety, fear anger or discomfort.
 - Measurements should be avoided if the child has a headache or fever or is receiving any medical treatment at the time of the study.
- 2.17 Chang et al (2012) investigated the effects of environmental noise on 24 hour ambulatory vascular properties in adults. Vascular properties include resistance, which is the resistance to flow that is needed to be overcome in order for blood to be pushed through the circulatory system. Vascular compliance and distensibility (elasticity) is the ability of a blood vessel wall to expand and contract passively with an increase of pressure and cardiac relaxation and pulsation. Early changes in vascular properties can be pre-cursors to identified conditions such as increased blood pressure, ventricular hypertrophy (muscle wastage) and arteriosclerosis (thickening and hardening of the artery walls).
- 2.18 The aim of this study was to monitor personal environmental noise dose, in this case mainly traffic noise as participants lived at least 10km from an airport, using a personal noise dosimeter (50 dBA to 120 dBA), and changes in vascular

properties using ambulatory non-invasive monitors worn on the wrist. Sixty six participants aged 18-32 years were recruited for the study from China Medical University in 2007. Participants answered a comprehensive screening questionnaire and refrained from smoking, caffeine, exercise, alcohol and listening to music for the duration of the study. The mean noise exposure for the daytime (0800-2300) was 61 dBA and for night-time (2300-0800) it was 48 dBA, with a 24 hour average of 56 dBA.

- 2.19 The results indicated that environmental noise exposure had temporary and sustained effects on vascular properties. There was an unexpected increase in arterial compliance during night-time, and a decrease in resistance during both daytime and night-time. Such changes were induced by present, 30 minute and 60 minute time-lagged noise exposures and contributed to the overall changes in vascular properties over a 24 hour period. The authors discuss possible theories as to why these changes occur, including as a reaction to stress-induced increased blood pressure, and interestingly as a possible response to noise-induced sleep disturbance. There was a lower arterial resistance at night-time compared with those measurements during the daytime among all subjects, which could explain the importance of noise disturbed sleep in cardiovascular diseases as sleep is an important modulator of cardiovascular function.
- 2.20 This is an important study as it is the first of its kind to provide evidence that environmental noise might affect structural changes in vascular properties that are related to hypertension. Although this study is not aircraft-noise specific it is possible that similar results may be observed as a response to aircraft noise and should be investigated in the future.
- 2.21 It is proposed that the physiological mechanism that is occurring may be that noise exposure causes the sympathetic and endocrine system to increase blood pressure. This then activates the muscular responses in arteries to allow for the surge of blood flow and to stabilise capillary pressure. It is these responses which produce the increased arterial compliance and decreased arterial resistance that subsequently prevent immediate damage within vessels.
- 2.22 In 2013 Babisch published a meta-analysis of noise and exposure-response curves between transportation noise and cardiovascular diseases. When considering epidemiological research approaches, Babisch stresses the importance of having a biological model for how the noise exposure could affect health and the need for different research methods to be used to assess the impact rather than using the same methodology and therefore the same error, each time. He also discusses the possibility of a threshold of effect, which may arise due to biological reasons, or possibly due to imprecision in data and small sample sizes. There is a need for the magnitude of effect to have implications for public health, and only then if all of these factors are accounted

for should a quantitative risk assessment including cost-benefit analysis should be employed to influence any decision-making processes.

- 2.23 For long-term noise exposure, Babisch updated his 2002 diagram representing the possible pathways that lead to health outcomes as a result of noise. In view of the experimental findings indicating that people do not physiologically habituate to noise exposure, even after being exposed for many years and even when they do not consciously report any disturbance during sleep for example, his updated model considers two pathways. The first is a non-conscious pathway via direct interactions of the acoustic nerve with the central nervous system, and the second is a conscious pathway via indirect physiological activation due to the emotional and cognitive reaction towards the noise. The theory is that both pathways result in changes in the autonomic and endocrine systems, resulting in unbalanced physiological and metabolic function, which may then result in cardiovascular disease in the long term. Babisch suggests that the indirect pathway may be dominant in people who are awake, and the direct pathway becomes dominant during sleep, and at much lower sound levels. This theory is represented in Figure 1.
- 2.24 Babisch produced a meta-analysis of results from road traffic and aircraft noise studies. Pooled effect estimates were derived from other meta-analyses on road noise and hypertension (24 studies, van Kempen and Babisch, 2012), road traffic and myocardial infarction (5 studies, Babisch, 2008), and aircraft noise and hypertension (5 studies, Babisch and van Kamp, 2009). Road traffic noise and stroke (Sørensen et al, 2011), and aircraft noise and myocardial infarction (Huss et al, 2011) each only contained one study, but were included in the analysis.
- 2.25 The exposure-response relationships are shown in Figure 2, and represent estimated relative risk with increasing sound level. The curves indicate that there is a higher risk of approximately 20-40% for those people where the weighted average outdoor level at the façade of their houses exceeds 65 dBA. Babisch suggests that if the difference between day and night noise levels is considered to be approximately 7-11 dBA, the findings can be converted to a night time noise level of 55 dBA. It should be acknowledged that there are wide variations between the onset of the exposure-response relationships, from L_{den} of 40 dBA to 60 dBA. It is of interest that that aircraft noise MI is such a higher risk than road traffic MI, yet the situation is reversed for hypertension, which is a known risk factor of MI. One critical factor in this research is that the very low aircraft noise exposure presented is an underestimate or was in the presence of other noise sources that were not accounted for.

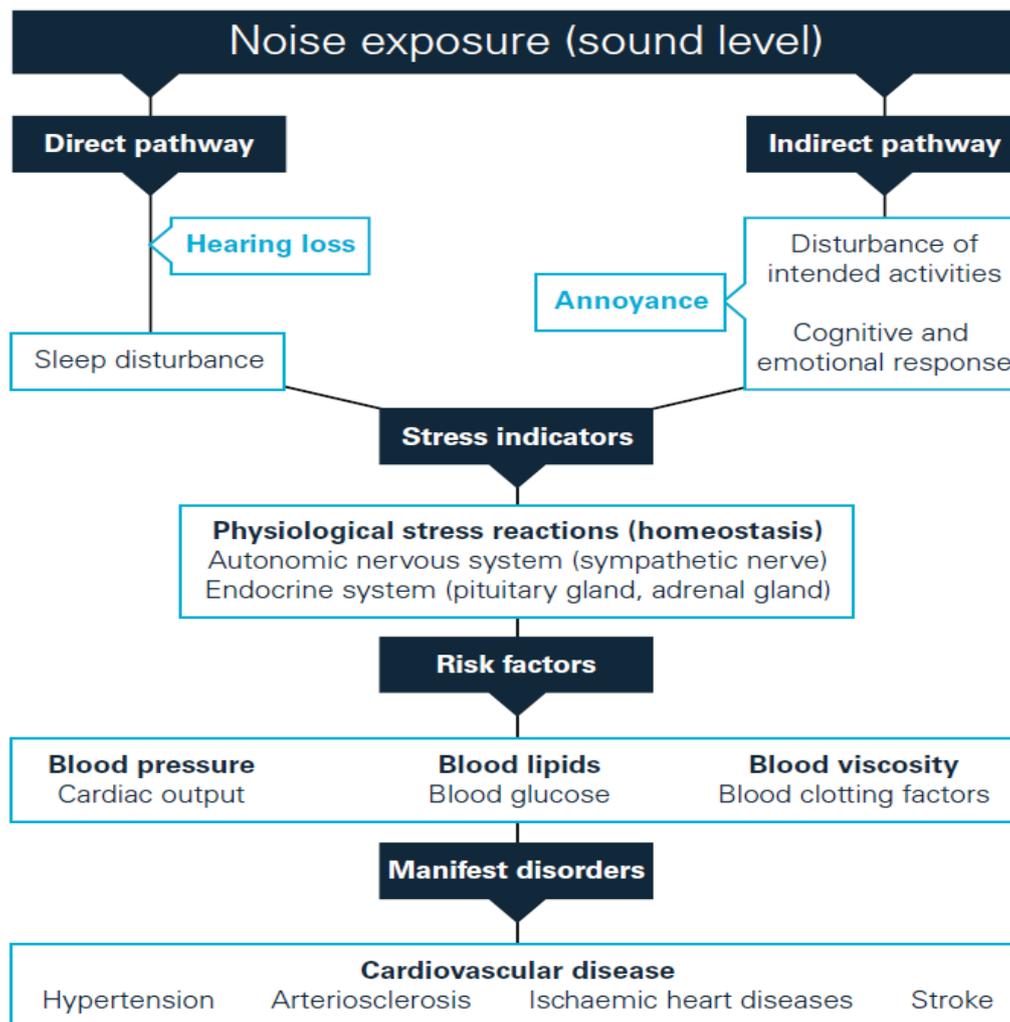


Figure 1: Noise reaction chart, updated version. Taken from Babisch, 2013.

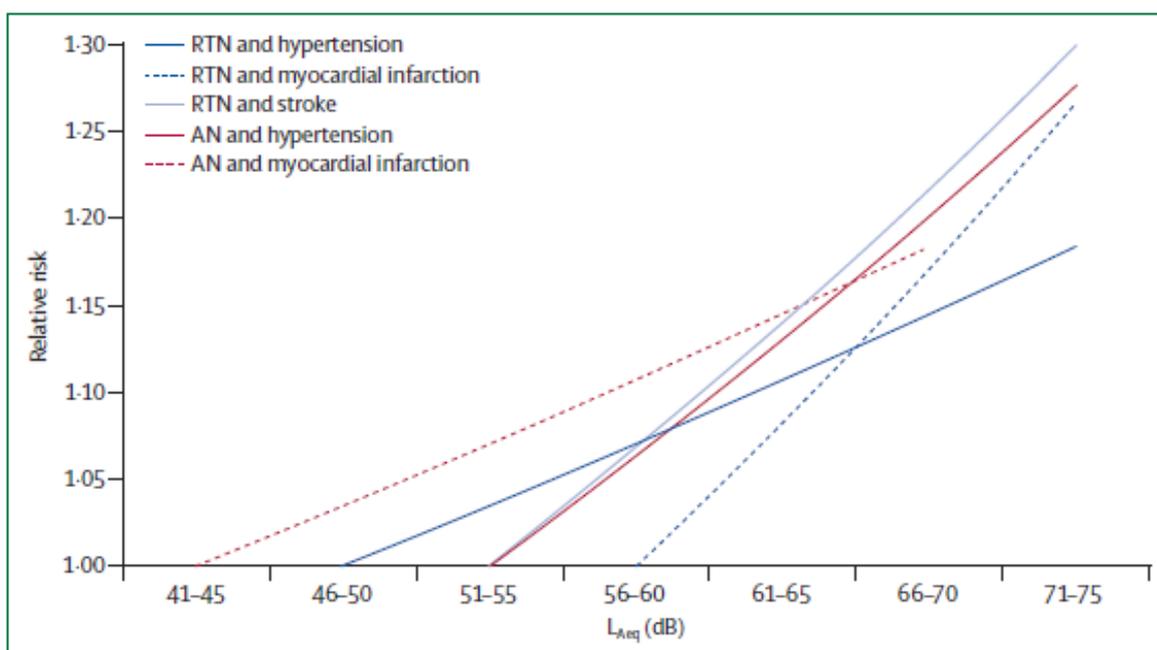


Figure 2: Exposure–response curves of road and aircraft noise and cardiovascular endpoints RTN and hypertension (24 studies, noise indicator LA_{eq} 16 h); RTN and myocardial infarction (five studies, noise indicator LA_{eq} 16 h); RTN and stroke (one study, noise indicator LDEN); AN and hypertension (five studies, noise indicator LDN); and AN and MI (one study, noise indicator LDN). RTN=road traffic noise. AN=aircraft noise.

- 2.26 Clearly, potential moderators and confounding variables need consideration in such research. These include location of rooms, windows being open or closed, length of residence, age, gender, and type of housing. Babisch suggests that future work should improve the noise assessment to consider secondary road networks and side streets, and quiet side dwellings should be included in the assessment. The issue of cumulative noise is important, i.e. it is critical to ensure that the dominant noise source is reflected in these types of studies. It is important that day-night differences should be investigated further, in relation to noise-induced sleep disturbance and development of cardiovascular diseases. Air pollution as a confounders or co-exposure also needs to be included in future work.
- 2.27 The findings from two UK studies focused around Heathrow airport were published in late 2013, and identified possible associations between aircraft-noise and health impacts on residents living in this vicinity.
- 2.28 The first was by Hansell et al (2013) from Imperial College, London which had the aim of investigating the association between aircraft noise and the risk of stroke, coronary heart disease and cardiovascular disease. The background to the research was that although there have been studies investigating cardiovascular effects of aircraft noise, the outcomes of those looking at stroke, coronary heart disease or cardiovascular disease are inconsistent. A possible reason for this may be due to a lack of statistical power because of the relatively small numbers of people exposed to high levels of aircraft noise.

- 2.29 This study examined comparisons between hospital admission rates for cardiovascular disease and mortality in neighbourhoods exposed to aircraft noise from Heathrow airport. Daytime (0700-2300) and night time (2300-0700) noise exposures were expressed as the average annual day LA_{eq} , 16 h and annual night LA_{eq} , 8 h respectively at a spatial resolution of 100 x 100 m, as estimated each year by the UK CAA and published by the Department for Transport. The study area included twelve London boroughs and nine districts to the west of London exposed to noise levels of at least 50dBA daytime (LA_{eq} , 16 h). For the twelve London boroughs data on air pollution in the form of particulate matter (PM10) at 20 x 20 m resolution, and road traffic noise at a spatial resolution of 10 x 10 m (LA_{eq} , 16 h) were also examined as potential confounding variables. Neighbourhoods were defined using the national census geographical units. The data on hospital admissions and deaths for 2001-2005 were obtained from the Office for National Statistics and Department of Health. The data for stroke, coronary heart disease and cardiovascular disease were then linked to postcode, geographic location and then noise exposure level. Confounders such as ethnicity, lung cancer (as a proxy for smoking) and deprivation were included.
- 2.30 Daytime aircraft noise and road noise was grouped into six categories from ≥ 51 to >63 dB in increments of 3 dB. For night time aircraft noise the increments were set at 5 dB intervals as less people were affected and categorised as ≤ 50 , >50 , and >55 dB. In order for a comparison between day and night time data to be made, daytime aircraft noise was also analysed using the same 5 dB groups. The study area covered 3.6 million people, only 2% living in the highest category of daytime or night time noise exposure.
- 2.31 The main findings on the hospital admissions with regard to stroke, coronary heart disease and cardiovascular disease are shown in Figure 3. With increased aircraft noise the risk of hospital admission also increased, with adjustment for ethnicity, deprivation and smoking included.

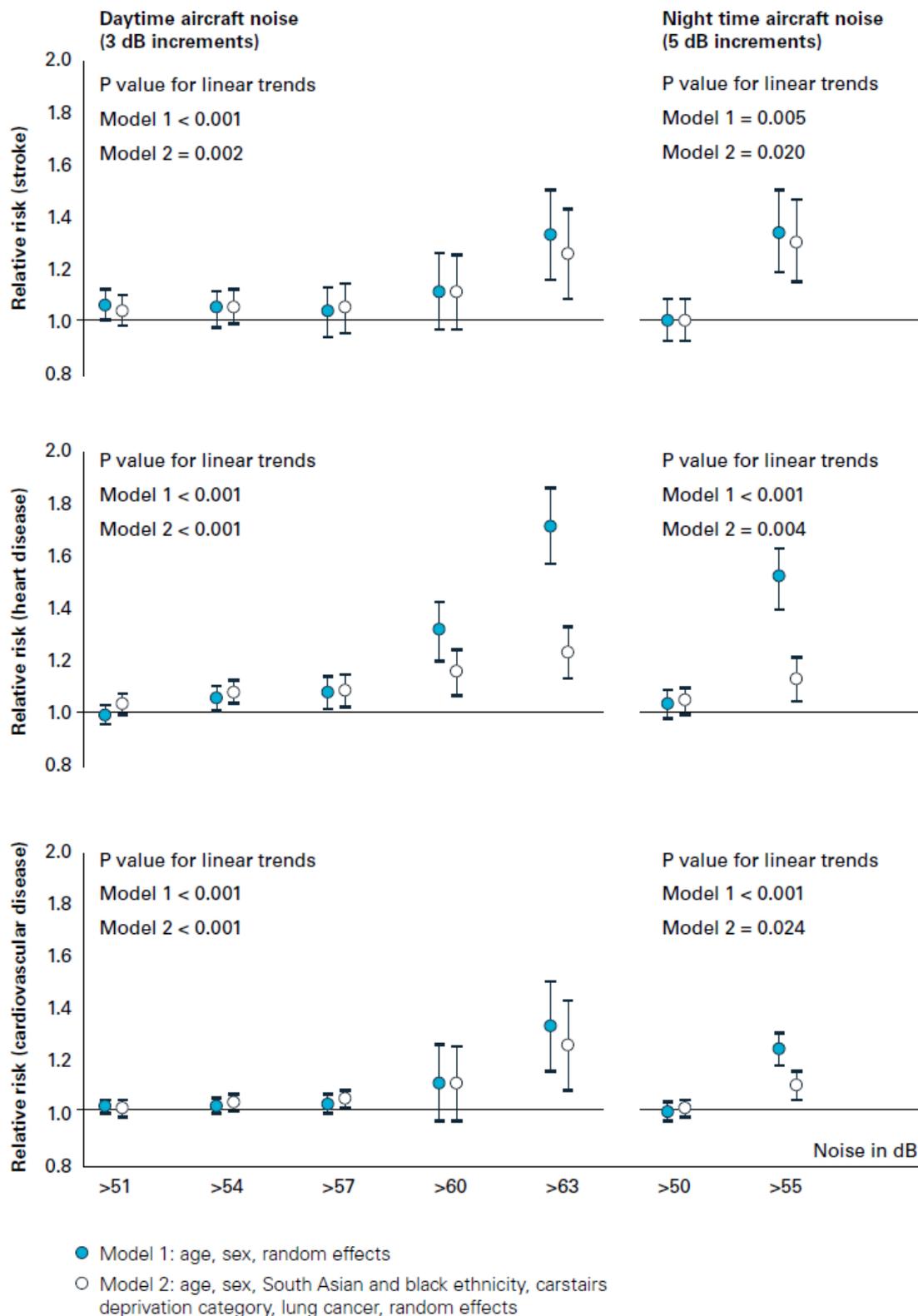


Figure 3: Relative risks for associations between hospital admissions for stroke coronary heart disease and cardiovascular disease between 2001 and 2005, and the annual weighted average daytime aircraft noise and night time aircraft noise in 2001 census output areas. Reproduced without permission from Hansell et al (2013).

- 2.32 The two sets of data illustrate the difference between the two types of adjustment for confounders. Model one represents adjustment for age, sex and random effects, and model two also includes ethnicity, deprivation and lung cancer. This separate analysis was chosen because the initial data highlighted that areas with a high proportion of South Asian and black ethnicity population were concentrated in the north eastern and eastern parts of the study area, which were also areas with higher deprivation and lung cancer risk.
- 2.33 Interestingly, adjustment for ethnicity, deprivation and lung cancer results in a much lesser degree of relative risk of hospital admissions particularly for coronary heart disease at noise exposure levels of more than 60 dB LA_{eq}, 16h. The same pattern is seen for cardiovascular disease, although to a lesser degree. It is important to consider the effect of ethnicity (in particular South Asian ethnicity, which is itself strongly associated with risk of coronary heart disease). The authors explained that when controlling for South Asian ethnicity in particular. It has a noticeable effect on these results, the effect due to noise exposure decreases quite dramatically. When comparing areas exposed to more than 63 dB LA_{eq}, 16 h to those exposed to 51 dB LA_{eq}, 16 h or less, the relative risk for hospital admissions due to stroke was 1.24 (1.08 to 1.43, 95% CI), for coronary heart disease was 1.21 (1.12 to 1.31, 95% CI) and for cardiovascular disease was 1.14 (1.08 to 1.20, 95% CI). The results for night time aircraft noise (>55 dB v ≤50 dB) were 1.29 (1.14 to 1.46, 95% CI), 1.12 (1.04 to 1.20, 95% CI) and 1.09 (1.04 to 1.14, 95% CI) respectively. When using the same categories for daytime and night time noise the results suggested higher relative risks for night time noise.
- 2.34 The corresponding results for relative risk of mortality were similar at the higher noise levels. In adjusted models for daytime aircraft noise (>63 dB v ≤51 dB) the relative risk for stroke mortality was 1.21 (95% confidence interval 0.98 to 1.49), for coronary heart disease was 1.15 (1.02 to 1.30), and for cardiovascular disease was 1.16 (1.04 to 1.29). The relative risks for night time aircraft noise (>55 dB v ≤50 dB) were 1.23 (1.02 to 1.26), 1.11 (0.99 to 1.24), and 1.14 (1.03 to 1.26) respectively. The results were unchanged with additional adjustment for PM10 and road traffic noise in the twelve boroughs of London. It was reported that the results obtained when using the same categories for daytime and night time aircraft noise indicated that the relative risks for mortality were higher for night time noise.
- 2.35 There are several issues to consider when interpreting the results from this study. Firstly, although road noise was included in the confounding variable analysis, rail noise was omitted which would have helped give a more representative group of noise confounders. Secondly, although the researchers have attempted to take into account the issue of confounding air pollution by including exposure to PM10, they did not include exposure to Nitrogen Dioxides (NO₂), possibly because NO₂ is primarily linked with respiratory disease rather

than cardiovascular disease. However, considering that NO₂ concentrations exceed EU Air Quality limits at a number of locations within the study area - including both factors would have enabled any confounding effects of air pollution to be more fully understood.

- 2.36 In terms of the noise categories, the increments ceased at 63 dB and above. It is unclear why this number was chosen as the cut-off point and levels such as 66 dB and 69 dB and above were all grouped together in this category and not analysed separately, even though there should have been sufficient population numbers in order to perform discrete analyses. It is possible, however, that this choice was due to statistical sampling issues, whereby there were not enough hospital admissions or mortality cases to be grouped into separate noise categories.
- 2.37 As mentioned briefly earlier, the differences in effect size between the two models is marked, especially so for relative risk of hospital admissions for all three outcomes but especially for coronary heart disease at exposure levels of more than 60 dB and more than 63 dB.
- 2.38 When looking at mortality risk, as opposed to risk of hospital admission, the relative risk actually decreases to less than 1.0, for the noise exposure between 57 and 60 dB LA_{eq}, 16h, for stroke and cardiovascular disease in both models, although this effect is more pronounced for stroke. This suggests the possibility of a further confounding variable that has not been taken into account. The results also suggest a higher risk of mortality from coronary heart disease than cardiovascular disease. This is counter intuitive given that cardiovascular disease encompasses all the diseases of the heart and circulation, including coronary heart disease and stroke along with heart failure and congenital heart disease. It would be expected that the largest effect would be seen for the category of cardiovascular disease, and stroke and coronary heart disease would show smaller effects, as they are subsets of this.
- 2.39 For the night noise data, the upper limit cut-off is noise exposure of at least 55 dB, but it is not explained as to why this is the case. This appears to encompass a large range of noise levels in just one category, for example the risk factor could occur at much higher levels such as 69 dB, yet there is no distinction to allow for this possibility within the analysis and it would benefit from the refinement of noise categories.
- 2.40 It is acknowledged within the paper that it was not possible to have access to individual level information on confounders such as smoking, so results at area levels may not be applicable to individuals. It was not possible for the study to distinguish between short and long term effects of noise and length of residency in this study, which would merit further research. A potential source of bias may be the lack of information concerning the migration in and out of the study areas.

- 2.41 The differences between night time noise and day time noise could not be distinguished due to their high degree of correlation. The authors suggested that further research is needed to assess whether night time noise affecting sleep may be contributing to the observed results. In addition to possible causal relationships between aircraft noise and cardiovascular outcomes, it is important to consider the potential for confounding and ecological bias in this study. An important area for further research would be to determine the relative contribution of night time noise compared with daytime noise to the respective health endpoint.
- 2.42 An independent review of this study was commissioned by the Department of Environment, Food and Rural Affairs (Defra) and conducted by Stansfeld et al (2014). The review concluded that the study added to the evidence supporting the link between aircraft noise, coronary heart disease, stroke and cardiovascular mortality yet the associations were inconsistent across all measures. The reviewers suggested that this may be due to the relatively small association between aircraft noise and cardiovascular risk and the various confounding issues that are inevitable found in studies of this nature.
- 2.43 Due to the fact that it was not possible to control for confounders on an individual level, it is important to note that the effect size reported may be subject to a degree of error. The reviewers recommended that the effect magnitudes reported in the study should not be used in subsequent economic analyses.
- 2.44 The second study that included health effects around Heathrow was by Floud et al (2013), again from Imperial College, London. This European study was an extension to the Hypertension and Environmental Noise near Airports (HYENA) study, using self-reported data on heart disease and stroke between 2004 and 2006 from 4,712 people living near six European airports. This study examined road traffic noise and aircraft noise around London Heathrow, Amsterdam Schiphol, Stockholm Arlanda and Bromma, Milan Malpensa, Berlin Tegel and Athens Elephtherios Venizelos with the aim of investigating whether there is an association between exposure to aircraft noise or road traffic noise and heart disease and stroke.
- 2.45 In the HYENA study residents around the given airport were exposed to ranges of noise levels between less than 50 dBA to more than 60 dBA $LA_{eq,16h}$. As part of the health questionnaire participants were asked to declare if they had ever been diagnosed with angina, myocardial infarction (MI) or stroke whilst at their current address. This represented the 'heart disease and stroke' factor within this study. Aircraft noise was estimated for annual average day time (0700-2300) $LA_{eq,16h}$ and night time (2300-0700) L_{night} and road traffic noise was estimated using the 24 hour metric $LA_{eq,24h}$. The lower limit cut-off levels were 35 dBA for daytime aircraft noise, 30 dBA for night time aircraft noise and 45 dBA for road traffic. The researchers appear to have chosen these very low noise exposures,

because the information seemed to be available. Such low exposure data have not been validated and are typically associated with long-distance sound propagation with associated large uncertainty. Secondly, the aircraft noise values are from aircraft noise sources alone. However, overall ambient noise exposure levels in urban and suburban areas rarely drop below 40dBA, so the cut-off levels are likely to be below ambient noise exposure levels in much of the study areas.

- 2.46 In those study, as a possible confounder, nitrogen dioxide (NO₂) was estimated at participants' addresses using dispersion modelling in the UK, Netherlands and Sweden.
- 2.47 The results indicated that 5.9% of the study population responded with self-reported heart disease and stroke, with the UK having the highest proportion of 8%. Night time aircraft noise was associated with self-reported heart disease and stroke but this effect was no longer present when controlled for confounding variables such as age sex, body mass index, education and ethnicity. Importantly, when the length of residence was included in the analysis, there was a significant association for those people who had lived at their current address for 20 years or more (odds ratio 1.25, 95% confidence intervals of 1.03 to 1.51) per 10 dBA increase in noise exposure. However, in contrast to night time noise, daytime aircraft exposure had no significant association with heart disease and stroke before and after controlling for confounders.
- 2.48 For road noise there was an increase in proportion of self-reported heart disease and stroke that remained after controlling for confounding variables, and length of residence did not appear to display effect modification for this noise source. Weak correlations were found between aircraft noise and NO₂ levels, with moderate correlations found between road noise exposure and NO₂. For participants who had lived at the same address for 20 years or more the association between night time noise and heart disease and stroke was significant after adjustment for NO₂. When NO₂ levels were factored into the analysis for subsamples of 24 hour road noise exposure, the significant association was lost, which suggested that NO₂ is a confounding variable in this relationship.
- 2.49 There are important points to consider when interpreting the results from this study. Firstly, the data are self-reported, which may lend itself to over or under-reporting and therefore increasing bias within the sample. Secondly, the lack of statistical significance between daytime aircraft noise and heart disease and stroke is striking and should not be overlooked. It was in fact close to zero association. Clearly this may be due to participants being away at work during the day and therefore not being necessarily exposed to the noise dose that their house receives during the day.

- 2.50 The finding that night time aircraft noise was not significantly associated with self-reported heart disease and stroke after adjustment for confounders is of significance. However, given the association for those residents who had lived at the same address for 20 plus years, the results suggest that the relationship between aircraft noise exposure at night may be strengthened over time, and could be cumulative in nature.
- 2.51 This study found that associations between road noise and heart disease and stroke were confounded by air pollution, although the associations between aircraft noise and heart disease and stroke remained robust even after adjustment for NO₂. This is not unexpected, since road traffic is the predominant contributor to NO₂ pollution exposure. In addition the results suggested that for road traffic noise and heart disease and stroke, age may be a modifier as an association was found for those participants aged over 65 years. This probably needs to be investigated further however, in larger samples with increased power and the inclusion of air pollution as a co-exposure.
- 2.52 Although this study attempted to analyse air pollution as a confounding variable, the choice to use NO₂ alone does not fully represent the effects of air pollution, as particulate matter is also associated with transport emissions. Finally, although education level was controlled for in this study, socioeconomic status such as income or area-level deprivation was not taken into account and may also be a confounding factor.
- 2.53 This study provides a valuable insight into the associations between road traffic and aircraft noise and these particular health outcomes. Although the results suggest a possible long-term effect of night time aircraft noise (>20 years) on self-reported heart disease and stroke, the possibility of bias and further confounding issues should be considered carefully. In terms of road traffic noise and heart disease and stroke it is important to take into account the possible confounder of air pollution and age as an effect modifier before any firm conclusions can be drawn.
- 2.54 In addition to the two UK studies a US study was recently published by Correia et al (2013) from Boston School of Public Health and Harvard University, investigating aircraft noise exposure and hospital admission rates.
- 2.55 The aim was to investigate whether aircraft noise exposure is linked with hospital admissions due to cardiovascular disease in people of 65 years of age or older. The sample population was Medicare enrollees that lived close to 89 airports within the US. In total just over 6 million people aged 65 or more, enrolled in Medicare and residing in the 2,218 postcodes close to the 89 airports were studied. This sample size corresponds to approximately 15% of the entire US population of older people. The researchers used information from the Medicare insurance claims to analyse details such as when participants were admitted, length of stay, primary reason for admission, age, sex, ethnicity and postcode. In

this study five specific types of cardiovascular disease were included: heart failure, heart rhythm disturbances, cerebrovascular events, ischemic heart disease and peripheral vascular disease. A total variable of cardiovascular disease admissions was defined as the sum of hospital admissions for all of these causes.

- 2.56 The noise data was obtained from noise exposure contours generated using the US Federal Aviation Administration's (FAA) Integrated Noise Model (INM), from 45 dB upwards. The metric used was the Day-Night Level (DNL) which adds a 10 dB penalty to night time noise (2200-0700). In addition the 90th centile was also included, which is the point at which 10% of the highest noise levels fall.
- 2.57 To address confounding variables such as socioeconomic status the researchers concluded that the percentage of Hispanic people and the median household income would be the two key variables included in the analysis. Air pollution in the form of particulate matter PM2.5 and ozone concentrations were included, as well as postcode level road density to control for road noise and road-related air pollution.
- 2.58 There were 2,218 postcodes (779 with both fine particulate matter and ozone data) and 6 027 363 Medicare enrollees residing within the 45 dB DNL contour of the 89 airports. The analysis was based on three regression models. Model 1 only accounted for individual variables such as age, sex and ethnicity, Model 2 also included postcode-level socioeconomic status and demographic variables, and Model 3 which in addition included pollution variables to Model 2. The results are shown in Figure 4.

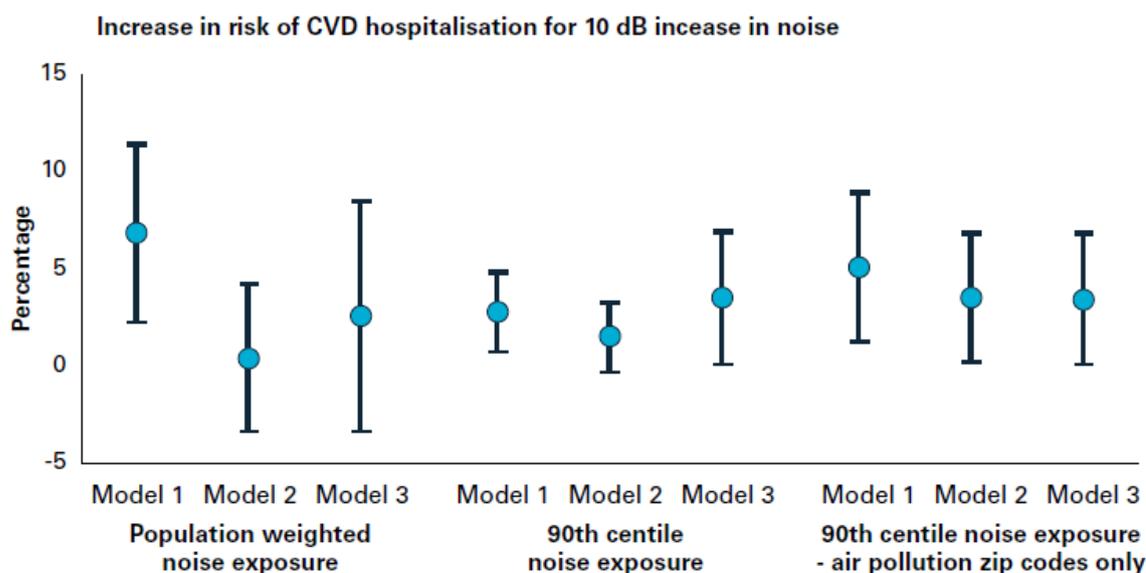


Figure 4: Overall estimates (averaged across 89 airports) of percentage increase in hospital admission rate for cardiovascular disease (CVD) associated with 10 dB (day-night sound level) increase in both exposure variables (population weighted noise exposure and 90th centile noise exposure) for each of the models. Model 1 controls for individual demographics (age, sex, and

race); model 2 additionally controls for postcode level socioeconomic status and demographics (% Hispanic and median household income); and model 3 adds to model 2 by also controlling for annual average fine particulate matter and ozone levels. Panel 3 shows models 1 to 3 fitted to only the 779 postcodes with both air pollution variables. Reproduced without permission from Correia et al (2013).

- 2.59 The results indicated that, for the 90th centile noise exposure category, when Model 1 was used which controlled for age, sex and ethnicity an increase of 10 dB was significantly associated with an increase of 2.9% in hospital admission rates. The significance decreased when controlling for additional socioeconomic status and demographic variables in Model 2 and was only marginally significant (1.6%). For model 3 which included air pollution, an increase in the 90th centile of noise of 10 dB was associated with an increase of 3.5% in the relative risk of cardiovascular disease hospitalisation. The third set of data points represent Models 1, 2 and 3 fitted only to those 779 postcodes where data for particulate matter and ozone were available and these also represented a statistically significant association with hospital admission for cardiovascular disease, suggesting that air pollution is not a confounding variable for these outcomes.
- 2.60 The points to consider when interpreting the findings are that the study employed a large sample size and therefore had substantial statistical power, compared to other cross sectional studies of this nature. It provides conflicting evidence to a previous study conducted around Schiphol airport, which found no evidence for increased hospital admissions due to aircraft noise exposure although it must be acknowledged that the Harvard study was able to assess individuals and account for a wider cross section of airports and populations and was also able to account for potential confounding effects of regional air pollution and near-road pollution and noise. The results also illustrated evidence for noise threshold for the observed increase in cardiovascular hospital admissions, with consistent statistically significant associations found only in the highest noise exposure group of 55 dB DNL and above.
- 2.61 An important limitation of the study is that the Medicare data used was developed for administrative purposes, and may be vulnerable to misclassification and discrepancies in management between areas. A further limitation is that the study did not control for smoking or diet, both of which are strong indicators for cardiovascular disease, due to the Medicare data not including this information. Socioeconomic status was calculated at an area level and therefore does not represent individuals in this data and from Census data from 2000, which is not necessarily representative of the most recent data from 2010.
- 2.62 The INM model has limitations also, due to the use of average annual noise level input which may mean that values could lack accuracy due to local acoustical variables not being accounted for.

- 2.63 This study did not differentiate between day time and night time noise exposure, in fact the noise variable, DNL, gives more weight to night time noise, so it was not possible to examine the role of night noise and potential sleep disturbance in hospital admissions, which may mediate the effects of aircraft noise exposure in relation to cardiovascular effects. Although the noise metric used incorporates a 10 dB penalty on night noise to reflect lower ambient noise levels at night, it would have been preferable to have separated out time of day effects in this sample and therefore no conclusions can be drawn from this data regarding night time aircraft noise exposure and cardiovascular hospital admissions in people aged 65 years and over.
- 2.64 Schmidt et al (2013) examined the effect of night time noise exposure on endothelial function and stress hormone release and the relationship with cardiovascular disease. The background to the study was the knowledge that in the case of aircraft noise, hypertension can be caused by the noise-induced stress release of hormones such as epi- and nor-epinephrine (adrenaline and nor-adrenaline) and/or the development of vascular (endothelial) dysfunction. Endothelial Dysfunction (ED) is considered one of the first steps towards atherosclerotic changes in the vasculature. As ED can be measured non-invasively, the aim of the study was to assess whether exposure to nocturnal aircraft noise may induce ED. A further measurement was the morning plasma measurement of adrenaline.
- 2.65 The study design used a blinded field study in 75 healthy volunteers (mean age 26 years), who were exposed at home, in random order, to one control pattern (no noise) and two different noise scenarios (30 or 60 aircraft noise events per night) with an average maximum noise level of 60 dBA L_{max} for one night each. Night time aircraft noise increased plasma epinephrine levels, worsened sleep quality, and decreased pulse transit time, a parameter of arterial stiffness, which varies inversely to arterial blood pressure. A dose dependent decrease in endothelial function after exposure to increasing levels of noise was also observed. Interestingly, a priming effect of aircraft noise on ED was observed, i.e. previous exposure to 30 noise events per night caused 60 noise events per night to have a larger effects on endothelial function. These data demonstrate that aircraft noise can affect endothelial function, and that rather than habituation, prior exposure to noise seems to amplify the negative effect of noise on endothelial function. Noise-induced ED may be in part due to the increased production in reactive oxygen species and may therefore be one mechanism contributing to the observed association of chronic noise exposure with cardiovascular disease.
- 2.66 The authors explain that the limitations of the study include no habituation nights, due to it being a field study and therefore this was not deemed necessary, and that the study sample was young, healthy adults, which is not representative of the whole population. However, the results from a healthy sample in this study

indicate the requirement for further investigation into aircraft noise and ED in populations with pre-existing cardiovascular diseases.

- 2.67 A recently published review in the *Lancet* (Basner et al, 2014) looked at auditory and non-auditory aspects of noise with a focus on potential mitigation measures and noise prevention methods. The review summarises the knowledge on auditory effects of noise such as occupational noise-induced hearing loss, tinnitus and age-related hearing loss. The non-auditory part of the review discusses the effects of environmental noise exposure on annoyance, cardiovascular disease, cognitive impairment in children and sleep disturbance. The review summarises the WHO work, which estimates that in western European countries at least 1 million healthy life years (disability adjusted life years, or DALYs) are lost every year due to environmental noise, with most being attributed to sleep disturbance and annoyance.
- 2.68 In terms of cardiovascular disease the review discusses chronic and acute effects of environmental noise exposure, with chronic exposure contributing to hypertension, ischaemic heart disease and stroke and acute exposure being associated with arousals of the autonomic nervous system and endocrine system. The general stress model is suggested as a pathway for reactions such as increases in blood pressure and the release of stress hormones, with mechanisms such as stress reactions due to discomfort (indirect) and non-conscious physiological stress from interactions between the central auditory system and other regions of the central nervous system (direct). It is suggested that the direct pathway could be the more likely pathway during sleep.
- 2.69 With chronic noise exposure, metabolism and the cardiovascular system are affected, with increases in cardiovascular risk factors such as blood pressure, blood lipid levels, viscosity and blood glucose concentrations. The authors report that these changes increase the risk of hypertension, arteriosclerosis and are linked to myocardial infarction and stroke. It is suggested that due to the different acoustic characteristics for different noise sources, there is a need for different exposure-response curves for the different noise sources.
- 2.70 Meta-analyses were previously conducted for road and aircraft noise, and the relationship with cardiovascular disease such as ischaemic heart disease (including myocardial infarction) and hypertension. The studies suggested increases in risk of between 7% and 17% per 10 dB increase in equivalent noise level LA_{eq} . Their results have been adjusted for known risk factors such as age, sex, socioeconomic status, smoking, body-mass index, and others. The researchers identified sex and age as effect modifiers. The dose-response curves for the meta-analyses were shown in Figure 2.
- 2.71 Another recently published review was on the cardiovascular effects of environmental noise exposure (Münzel et al, 2014). Basner is also a co-author on this review and there are many similarities with the *Lancet* paper, although

this review focuses solely on cardiovascular impacts of noise. The stress model is proposed as a mechanism for the pathway between environmental noise and cardiovascular responses, with the activation of two hormonal systems that help the body to cope with the stressor. These include the activation of sympathetic responses (flight or fight reactions) as well as the release of corticosteroids (defeat reaction). When people are exposed to very sudden or very loud noises e.g. low flying military aircraft noise, that can be perceived as aggressive or threatening, the fight or flight reaction is triggered. As a result, adrenaline and nor-adrenaline are released. Conversely, high-level noise events beyond the pain threshold and frightening sounds at lower levels increase plasma cortisol, the defeat reaction, aimed at mitigating the damages expected from the stressor. Such stress responses can result in changes in a number of physiological functions and in the homeostasis of several organs, including blood pressure, cardiac output, blood lipids, glucose, electrolytes and others.

- 2.72 The review explains the presence of nocturnal cortical arousals that result from noise as part of the Ascending Reticular Activating System, which is part of the body's arousal system. It receives input from several sensory systems, including the auditory system and relays this information to other parts, such as the cardio-respiratory network and through the Thalamus to the Cortex. It is explained that we recognise, evaluate, and react to environmental stimuli even when we are asleep and if such information is passed to the Cortex it can result in a cortical arousal which may disturb or fragment sleep. Interestingly, this is the reason that noise events do not result in an 'all or nothing' response, and not every event will lead to an awakening, but there can be a range of responses depending on the processing of the stimuli.
- 2.73 The differences in arousals between various types of environmental noise (road, rail and air) are discussed, with aircraft generally less likely to induce cortical or vegetative (e.g. heart rate and blood pressure) arousals compared to road or rail noise at the same Sound Pressure Level SPL. Despite this, aircraft noise is known to illicit higher annoyance responses than the other modes of transportation. The question of habituation is discussed, and generally speaking there is strong evidence for habituation to noise, for example, less arousals being observed in the field setting compared to the laboratory, and differences in responses between first study nights and subsequent nights. It is stressed; however, that habituation is not complete as people react to noise even after several years of exposure in the same environment. There is little known about the individual differences in the ability to habituate to noise, and arousals are still observed even after apparent habitation. Reactions such as increases in heart rate and blood pressure are known to habituate to a lesser degree than cortical arousals.
- 2.74 The review discusses the nocturnal effect of noise on the cardiovascular system and highlights the importance of the findings of Schmidt et al (2013) for

supporting a link between nocturnal noise exposure and cardiovascular disease. In addition, it is explained that a sustained decrease in blood pressure during the night (dipping) is important for resetting the cardiovascular system and therefore for cardiovascular health. If environmental noise causes cortical arousals, sleep fragmentation and/or awakenings this may prevent the blood pressure dipping process and contribute to the risk for developing hypertension in those people exposed to night noise for prolonged periods. The authors suggest that there is sufficient evidence for nocturnal environmental noise effects on the cardiovascular system, autonomically in the instances of increases in heart rate and blood pressure, and directly, in terms of vascular function through endothelial dysfunction, that a biological rationale is provided for the increased risk of hypertension, myocardial infarction and stroke in those people with long-term exposure to sufficient noise levels.

- 2.75 Details concerning some of the limiting factors when researching noise and health effects are discussed, such as exposure-modifying factors such as length of residence, room location, sleeping with windows open or shut and presence of insulation. Co-exposures and multiple noise sources are also issues that need to be considered. The authors suggest that noise mitigation policies should consider the health implications of environmental noise exposure, and such strategies should be to improve noise reduction at source, active noise control, optimised traffic operations, planning consideration and improved sound insulation and limit values.
- 2.76 In late 2015 some of the results of the much-awaited NORAH (NOise-Related Annoyance, cognition and Health) study were published. This is a large-scale, longitudinal German study that commenced in April 2011 and continued until 2014 and included 43 researchers from 11 institutes. In order to get more insight into the effects of transportation noise, the state-owned Environment & Community Center (ECC) of the Forum Airport and Region (FFR) commissioned the authors to conduct a noise effects monitoring program at Frankfurt Airport before and after the opening of a fourth runway.
- 2.77 The study examined:
- Aircraft noise annoyance and health related quality of life (HQoL) before and after the opening of the fourth runway in comparison to annoyance at other airports;
 - Comparison of HQoL and annoyance due to aircraft, railway and road traffic noise; effects of combined transportation noise exposure on annoyance and HQoL;
 - Effects of transportation noise on hypertension and cardiovascular diseases and the causal structure of noise exposure, noise reactions, and health effects;

- Effects of changing nocturnal noise exposure at Frankfurt Airport on sleep;
- Noise effects on cognitive performance and quality of life (QoL) in children.

2.78 Three work packages are included in the study:

1. Annoyance and quality of life
2. Sleep and health
3. Children's cognition

2.79 The results from the sleep and children's learning studies will be reported in their respective chapters within this report. As part of the health work package, a blood pressure monitoring study was conducted from July 2012 -July 2013, and July 2013 -2014 with participants residing in the vicinity of Frankfurt airport and who were exposed to at least 40 dB during the day. Over 800 participants were trained on the use of blood pressure meters that were connected to mobile telephones in real time, and recorded their own blood pressure measurements each morning and evening for three weeks and then again one year later. In addition, participants completed a questionnaire with information on basic diseases, socioeconomic status, medication, lifestyle, body dimensions and self-reported noise sensitivity.

2.80 The researchers found no significant link between aircraft noise exposure and blood pressure, heart rate or pulse pressure. Similarly, no significant relationship between road or rail noise exposure and the named outcomes was found.

Chapter 3

Children's learning

- 3.1 Annoyance in children has rarely been studied; however one study by van Kempen et al, 2009, investigated annoyance reactions and exposure-response relationships to aircraft and road noise in both home and school environments. Data from the Road Traffic and Aircraft Noise Exposure and Children's cognition and Health (RANCH) study was used, with a secondary aim to compare children's annoyance reactions with those of their parents. Both parents and children's reactions were measured using self-administered questionnaires. The study was done on 2844 children, aged 9-11 years from primary schools in areas surrounding London Heathrow, Amsterdam Schiphol and Madrid-Barajas airports. Aircraft noise exposure at home and school was significantly related to severe annoyance, in both cases where the noise exposure from aircraft was higher, the proportion of severely annoyed children was higher also. At school, the percentage of severely annoyed children was predicted to increase from 5% at 50 dBA L_{eq} 0700 - 2300 to about 12% at 60 dBA L_{eq} 0700-2300. At home these figures were 7% and 15% respectively. Road traffic noise at school was also significantly related to severe annoyance, with the percentage severely annoyed children predicted to increase from 4% at 50 dBA L_{eq} 0700-2300 to about 6% at 60 dBA L_{eq} 0700 - 2300. The association between annoyance and aircraft noise is stronger in children than road noise, probably due to the intensity, variability and unpredictability of aircraft noise in comparison to road noise. Children's annoyance reactions were found to be comparable to their parent's reactions, but with children having lower response rates of severe annoyance than their parents at higher noise levels of 55dB and above.
- 3.2 Van Kempen and van Kamp (2010) also studied the role of annoyance in the relationship between transportation noise and children's health and cognition. The aim of this study was to investigate whether annoyance may have been involved in the association between noise and cognitive functioning and health in the Road Traffic and Aircraft Noise exposure and Children's cognition and Health (RANCH) project. Children's health was measured by a symptom list and resting blood pressure as part of a physical examination. Cognitive testing was measured with various tests from the Neurobehavioral Evaluation System (NES). There were four main objectives of the study:
- To investigate the relationship between aircraft and road traffic and perceived health.
 - To investigate whether annoyance is an intermediate step in the relationship between noise and cognitive functioning and health.

- To investigate whether annoyance confounds the association between noise and cognitive functioning and health.
- To investigate whether the relationship between noise and health and cognitive functioning differs between different annoyance groups.

- 3.3 The methodology used in the RANCH project has been described in previous reports ([ERCD Report 0908](#)) and in various research papers. In brief, the final sample contained 2,844 children aged 9–11 years attending 89 primary schools in areas around Heathrow Airport, UK, Schiphol Airport, Amsterdam and Madrid-Barajas Airport, Spain. Schools were selected according to the modelled air and road traffic noise exposures of the school area expressed as LA_{eq} , 0700-2300 h, and were matched on indicators of socio-economic status (SES) and ethnicity. Written consent was also obtained from the children. Blood pressure was taken in the UK and The Netherlands only, and the NES test batch was only administered in the Netherlands sample. All children were given a questionnaire for their mother or primary carer to complete at home concerning the child's health and behaviour, annoyance and possible confounding factors such as length of residence, window glazing, socioeconomic status etc.
- 3.4 The results indicated that UK schoolchildren were more annoyed due to aircraft noise at school than the Dutch and Spanish children (32%, 18% and 18% respectively). No direct associations were found between noise exposure at school and self-reported health symptoms: both air traffic and road traffic noise exposure at school were not related to a statistically significant increase in the number of symptoms. The relationship between noise and neurobehavioral functioning and health was not confounded by annoyance: the association with noise hardly changed after additional adjustment for annoyance. Associations were found between annoyance and self-reported health symptoms and the outcomes of several NES tests: children who were annoyed, reported more health symptoms compared to children who were not annoyed; children who were annoyed due to air traffic noise at school made significantly more faults at the Switch condition of the Switching Attention Test, and the span length of these children was also significantly shorter on the digital memory span test. Children who reported annoyance due to noise at school had a lower blood pressure compared to children that reported no annoyance. Finally, the relationship between noise and health and neurobehavioral functioning did not differ between different annoyance groups.
- 3.5 The authors explain that the findings suggest that noise may not only directly affect aspects of neurobehavioral functioning but that they also may be a result of levels of annoyance. In this study, this is illustrated by the findings that children who were annoyed due to air traffic noise at school made significantly more errors on the Switching Attention Test (SAT) compared to those children who were not annoyed due to aircraft noise at school. The results for the children

in Amsterdam were also reported separately by van Kempen et al (2010) and were consistent with this finding on the SAT for the overall sample. This was also the case for the digital memory span test, with children that were annoyed due to aircraft noise at school having a shorter memory span length than those children not annoyed.

- 3.6 The blood pressure results were somewhat surprising in this study. Annoyance was not found to be a modifier of the association between noise exposure and blood pressure. Furthermore, annoyance was associated with decreases in blood pressure, and the observed differences between noise and blood pressure between annoyance groups were not significant. The decrease in blood pressure in the annoyed group does not fall into the expected outcomes of the general stress model where a subjective assessment of the stressor contributes to a stress outcome such as increased blood pressure.
- 3.7 There are several limitations to this study, such as potential misclassification of noise exposure with each child being assigned to school addresses which were linked to modelled equivalent aircraft and road traffic noise levels. Whilst, aircraft noise exposure is relatively uniform throughout the day at the airports studied, road traffic exposure may be subject to flow variations throughout the day. A further limitation is that this study only considered noise exposure at school, and clearly the children will spend a large part of their time at home. Part of this time will be spent sleeping, and it is possible that noise-induced sleep disturbance at home may be a contributing factor towards the performance decrements observed in the cognitive tests. However, the authors stress that aircraft noise levels were available at home for each of the three study locations, and road traffic at home only for the Dutch sample. In each of the three study locations, a high correlation was observed between aircraft noise levels at home and at school ($r = 0.83-0.95$). Due to the high correlation between the air traffic noise metrics, it was not possible to disentangle the effects of school and home noise exposure on perceived health in this study. Finally, there is a chance of recall bias in the self-reporting of symptoms on the health assessment aspect to this study.
- 3.8 The RANCH study was one of the largest investigations into the effects of environmental noise and children's cognition, and it is not surprising that the data has been used for much further analysis into this area. Stansfeld et al (2009) investigated the relationship between aircraft and road traffic noise exposure and children's mental health as part of a further analysis on data from the RANCH cohort. Stansfeld examined in more detail the sub-categories of the Strengths and Difficulties Questionnaire (SDQ) which is a well-established tool for analysis of psychological symptoms in children. Previous work has suggested there may be a link between aircraft noise and hyperactivity, although this was not found in another study investigating the same outcomes. As previously reported, the RANCH study looked at primary school children living around Heathrow,

Schiphol and Madrid airports. 2844 pupils aged 9-10 years from 89 schools in total participated in the study. In each country primary schools were selected according to their noise exposure ranging from low exposure to high exposure for both road traffic and aircraft noise; 30-77 dBA L_{eq} for aircraft noise and 32-71 dBA L_{eq} for road traffic noise. All schools were matched according to socio-economic status and ethnicity within each country. There was no significant association between either aircraft or road traffic noise exposure and mental health measured by the total SDQ score. Aircraft noise was statistically significantly associated with higher scores on the hyperactivity subscale after full adjustment, and this effect differed significantly across countries and was strongest in the Netherlands. There was also a significant inverse relationship between road traffic noise and conduct behaviour, which was a surprising result. The results indicated that aircraft and road noise do not affect the children's overall mental health measured with this questionnaire; higher levels of aircraft noise were associated with higher scores on the hyperactivity subscale and higher levels of road traffic noise exposure were associated with lower scores on the conduct problems subscale. The authors stress that this finding needs further study and replication to be able to suggest a consistent link.

- 3.9 Stansfeld et al (2010) also examined the effect of night-time aircraft noise exposure on the cognitive performance of children. This analysis was also an extension of the RANCH study, and the Munich study in which 330 children were assessed on their cognitive performance in three waves, each a year apart, before and after the switch over of airports. Aircraft noise exposure and self-reported sleep quality measures were analysed across airports to examine whether changes in night-time noise exposure had any impact on reported sleep quality, and if this was then reflected in the pattern of change in cognitive performance. In the Munich study, analysis of sleep quality questions showed no evidence of interactions between airport, noise and measurement wave, which suggests that poor sleep quality does not mediate the association between noise exposure and cognition. In the RANCH study, there was no evidence to suggest that night noise had any additional effect to daytime noise exposure. The authors explain that this investigation utilised secondary data and therefore was not specifically designed to investigate night time aircraft noise exposure on cognitive performance in children, but the results from both studies suggest that night time aircraft noise exposure does not appear to add any further deleterious effect to the cognitive performance decrement induced by daytime noise alone. They recommend that future research should be focussed around the school, for the protection of children against the effects of aircraft noise exposure on performance.
- 3.10 Crombie et al (2011) reported on the effects of environmental noise exposure, early biological risk and mental health in nine to ten year old children. As in the paper described above, data was taken from the RANCH sample and mental

health was assessed using the parental version of the Strengths and Difficulties Questionnaire (SDQ). The background to this study included research by Lercher et al, who found an interaction between early biological risk and ambient neighbourhood noise (predominantly road and rail noise at home) in children who were born prematurely or were of a low birth weight reported more mental health problems than those without this early biological risk. In their study ambient neighbourhood noise was estimated for the child's home address, however, a large part of a child's day is spent at school where they may also be exposed to environmental noise. It is therefore possible that the moderating effect of early biological risk found by Lercher et al may also exist for the relationship between noise exposure at school and mental health. The RANCH study had data available for aircraft and road traffic noise at school making it possible to look at the individual contributions of noise from these sources to the effect of early biological risk on mental health. The aim of this study was to investigate whether early biological risk moderates the relationship between road traffic noise or aircraft noise at school and mental health. Birth weight and gestation period were merged to create a dichotomous variable assessing 'early biological risk', in 1900 children from the RANCH cohort.

- 3.11 No interaction was found between either road traffic or aircraft noise at school and early biological risk for mental health outcomes. Nevertheless a main effect of early biological risk on mental health was found. The authors suggested that the findings surprisingly did not support those of Lercher et al, this in their view was due to the transient nature of aircraft noise compared to the more steady state sound levels of neighbourhood noise. Data from the RANCH study suggests that children with early biological risk; that is those born prematurely or with a low birth weight, have a greater chance of developing certain mental health outcomes but are not more vulnerable to the effects of aircraft and road traffic noise at school on mental health. The authors highlight the need to develop understanding of the pathways through which early biological risk might operate within future studies.
- 3.12 RANCH did not consider air pollution as a confounding factor. Clark et al (2012) therefore examined whether air pollution exposure at school (nitrogen dioxide) is associated with poorer child cognition and health, and whether adjustment for air pollution explains or moderates the previously observed associations of aircraft and road traffic noise at school on children's cognition in the 2001-2003 RANCH project. This secondary analysis of a sub-sample of the UK RANCH sample examines 719 9-10 year old children from 22 schools around London Heathrow airport, for whom air pollution data was available. This study had four aims. Firstly, to examine the correlations of aircraft noise exposure and road traffic noise exposure at school with air pollution measured at school for the UK RANCH sample. Secondly, to examine whether air pollution at school (NO₂) was associated with poorer child cognition and health outcomes in the UK RANCH

sample. The hypothesis was that air pollution would not be associated with impaired cognitive function and health. The third and fourth aims were to examine whether adjustment for air pollution at school would explain or moderate the previously observed associations of aircraft and road traffic noise exposure at school on children's health and cognition. Data was analysed using multi-level modelling. Air pollution exposure levels at school were moderate. They were not associated with a range of cognitive and health outcomes and did not account for, or moderate, associations between noise exposure and cognition. Aircraft noise exposure at school was significantly associated with poorer recognition memory and conceptual recall memory after adjustment for nitrogen dioxide. Aircraft noise exposure was also still associated with poorer reading comprehension and information recall memory after adjustment for nitrogen dioxide. Road traffic noise was not associated with cognition or health before or after adjustment for air pollution. Moderate levels of air pollution do not appear to confound associations of noise on cognition and health but further studies of areas that have higher air pollution levels are needed.

- 3.13 Xie and Kang (2012) published results of a study examining the environmental noise impact on academic achievements of students within inner and outer London areas. The aim of this study was to investigate the relationships between environmental noise levels of schools and a set of academic achievement factors and to determine the noise exposure of schools. Secondary schools in Greater London were studied. Four academic achievement indicators were considered, namely the average total point score per pupil of Key Stage 4, Contextual Value Added (CVA) score, overall and persistent absence. Five noise indicators were obtained after processing London noise map data, where road noise is the predominant noise source and the metric used is L_{den} . The results show that in the studied schools, the environmental noise levels have almost no significant relationships with the academic achievement indicators studied. As expected, the secondary schools in Inner London are noisier than those in Outer London, with an average difference of 2 dBA.
- 3.14 Seabi et al (2012) published research from South Africa on aircraft noise exposure, children's reading comprehension and the moderating effect of home language. Africa has eleven official languages, and although the majority of education is conducted in English followed by Afrikaans, there is a majority of the population (74%) that speak an indigenous (African) language as their first language. Therefore, for many pupils, English is their second and sometimes even their third language, which they may not be proficient in. Thus, English second language (ESL) learners may be at a double disadvantage, having to read and comprehend in their second language and simultaneously having to contend with background air traffic noise. The purpose of this study was to investigate the impact of chronic aircraft noise exposure and the moderating effect of home language on the learners' reading comprehension. The sample

comprised 437 (52%) senior primary pupils exposed to high levels of aircraft noise (Experimental group) and 337 (48%) pupils residing in a quieter area (Control group). Of these, 151 pupils in the Experimental group spoke English as a first language (EFL) and 162 spoke English as a second language (ESL). In the Control group, the numbers were similarly divided. A univariate General Linear Model was used to investigate the effects of aircraft noise exposure and language on reading comprehension, while observing for the possible impact of intellectual ability, gender, and socioeconomic status on the results. A significant difference was observed between ESL and EFL pupils in favour of the latter ($F_{1,419} = 21.95, P = .000$). In addition a substantial and significant interaction effect was found between the experimental and control groups for the two language groups. For the EFL speakers there was a strong reduction in reading comprehension in the aircraft noise group. By contrast this difference was not significant for the ESL speakers. The findings are somewhat counterintuitive, the authors suggesting that factors such as learner motivation and access to learning resources could differ between EFL and ESL pupils and explain the findings, and may be worth future investigation alongside the moderating effect of home language. .

- 3.15 Clark et al (2013) examined the longitudinal effects of aircraft noise on children's health and cognition, via a follow-up study to RANCH six years after the original data was collected in 2001 - 2003, when the study sample of children were in secondary school. Longitudinal studies of environmental noise and children's learning are lacking, and there is a need for research in this area to examine if the associations between noise and cognition strengthen over time. Longitudinal studies can also help increase understanding of the causal pathways between noise and cognition and health, assist in the design of mitigation strategies, and to further inform policy. This study had three aims:
- To examine whether aircraft noise exposure at primary school showed longitudinal associations with reading comprehension, noise annoyance, and psychological health at follow-up six years later.
 - To examine cross-sectional associations of aircraft noise exposure at secondary school on reading comprehension, noise annoyance, and psychological health, as few studies to date have examined noise associations on the health and cognition of children in this age group.
 - To examine associations between cumulative aircraft noise exposure at primary and secondary school and reading comprehension, noise annoyance, and psychological health, to assess the combined effect of aircraft noise exposure across the child's schooling.
- 3.16 The authors hypothesised that those children attending each of the exposure categories (aircraft noise at primary school, aircraft noise at secondary school, and cumulative exposure) would exhibit poorer reading comprehension, higher

noise annoyance and higher hyperactivity scores than children attending low aircraft noise exposure schools.

- 3.17 The follow-up study took place in 2008 and 27 secondary schools participated, compared to 29 primary schools that were part of the original RANCH study. For both studies, aircraft noise estimates were based on $LA_{eq,16h}$ outdoor contours that were provided by the UK CAA. These give the average noise exposure in dBA between 7 am and 11 pm for the school postcode. Baseline data were from July to September 1999; follow up data were from July to September 2007. Measurements of reading comprehension, psychological health, and noise annoyance were taken at the follow-up study. Sociodemographic factors that were assessed at baseline were also controlled for in the follow-up study. The response rate was 45%, with 461 subjects of a possible 1015 agreeing to take part. Baseline aircraft noise ranged from 34 dBA to 68 dBA with a mean exposure of 54 dBA. Follow-up aircraft noise exposure ranged from <50 dBA to 65.4 dBA with a mean exposure of 54 dBA. Overall, the majority of the children attended primary and secondary schools with similar noise exposure levels: 51.4% in the <51 dBA exposure category; 60.5% in the 51- 56.9 dBA exposure category; and 64.4% in the 57- 62.9 dBA category.
- 3.18 The main findings were that children exposed to aircraft noise at primary school reported significantly higher noise annoyance six years later at secondary school, even after taking noise annoyance at primary school into account. There were non-significant negative associations found between exposure to aircraft noise at primary school and poorer reading comprehension, but no association was observed between exposure to aircraft noise at primary school and poorer psychological health. Cumulative aircraft noise exposure at school and aircraft noise exposure at secondary school also showed significant associations with higher noise annoyance responses at secondary school, as well as non-significant negative associations with reading comprehension and no associations with psychological health.
- 3.19 The authors suggested that the non-significant negative association between aircraft noise exposure and reading comprehension may in part be due to the sample size, as the statistical coefficients were of similar size to those found in the primary school sample, yet were not significant in this sample, which suggests that large samples may be required for conclusively demonstrating noise effects on children's cognition. It is suggested that for future studies larger samples should be followed over time to assess whether associations of noise exposure in primary school on cognitive performance in secondary school can be found, as well as the further investigation of cumulative exposure.
- 3.20 No link was found with aircraft noise exposure in primary school, secondary school and cumulatively with psychological health and hyperactivity. The major limitation of this study was the degree of participant attrition between the

baseline study and follow-up. Half of the sample was lost due to being untraceable after primary school, lack of school participation, or due to pupil absenteeism. This may have implications for underestimation of the observed effects for cognition and health later in the children's lives. Other limitations include the fact that the secondary schools may not be entirely representative of the population or of aircraft noise exposure as the sample was not selected on the basis of secondary school noise exposure. Further limitations include a lack of data about aircraft noise exposure at the child's home at follow-up; about internal classroom acoustics and about secondary school road traffic noise exposure or air pollution.

- 3.21 Seabi (2013) also conducted a prospective study into children's health and annoyance reactions to aircraft noise in South Africa. The aim of this study was to examine health and annoyance reactions to a change in chronic aircraft noise exposure and to investigate whether any effects would persist over time or be reversed following the relocation of Durban airport, and therefore a stop to noise exposure from aircraft.
- 3.22 Over 700 children with a mean age of 11.1 years participated in the first Wave of the study in 2009, 649 in Wave 2 (mean age 12.3 years) in 2010 and 174 in Wave 3 in 2011 (mean age 13.3). Wave 2 and 3 occurred following the relocation of the airport. The children in the present study came from five co-education public schools that were selected according to the noise exposure of the school area. Two highly exposed schools (HN group) were selected as the study population for the aircraft noise exposure area. The windows, walls, façade of the schools were not sound insulated. The low noise group comprised schools in locations not exposed to aircraft noise, but that matched the socio-demographic characteristics (such as age, language spoken at home, and social deprivation) of the high noise group. The baseline L_{eq} noise measurements for the High Noise groups at the noise exposed schools near the flight path (Wave 1) varied from 63.5 to 69.9 dBA L_{eq} . Maximum noise levels varied from 89.8 to 96.5 dBA L_{max} . Low noise groups for Wave 1 were between 54.4 and 55.3 dBA L_{eq} and 73.2–74.3 dBA L_{max} . Noise measurements during Waves 2 and 3 when aircraft were no longer at the previous location produced results at the formerly noise exposed schools of 55.2 dBA L_{eq} and maximum noise levels of 60.8 to 71.2 dBA L_{max} . Levels at the quieter schools were averages of 50.5 to 57.9 dBA L_{eq} and 60.6 to 70.5 dBA L_{max} .
- 3.23 The findings showed that children within the HN group continued to perceive a substantial amount of noise despite the relocation of the airport compared to those in the LN group at school. Although there was no significant difference in the perception of noise between the groups at Wave 1 at home, pupils in the LN group perceived greater noise levels than their counterparts at Wave 2 and Wave 3. The findings supported some of those found by Clark et al (2013) in the follow-up to RANCH, with the children who were exposed to chronic aircraft

noise continued to experience significantly higher annoyance than their counterparts in all the waves at school, and only in Wave 1 and Wave 2 at home. Finally, despite the LN group exhibiting poor health scores at Wave 1 (a result which is unexpected and not understood), there was no significant difference between the groups on health outcomes in Wave 2 and Wave 3. The author suggests that chronic aircraft noise exposure may have a lasting effect on children's annoyance, but not on subjective health measurements. As with the RANCH follow-up study, there was a degree of attrition in this study, particularly for Wave 3 due to permission to follow-up children in Grade 8 (i.e. new schools) not being granted by some of the school teachers, as well as the bad weather during the assessment day, which resulted in many children not attending school. Noise exposure was only measured at schools and not at children's homes and finally the study only focuses on one source of noise. Suggestions for future longitudinal research includes measuring other sources such as road traffic noise, construction etc.

- 3.24 Although not aircraft noise-based or strictly cognitive, another recent paper described the results from the GINIplus and LISApplus German studies, looking at road traffic noise and children's behavioural problems and sleep disturbance (Tiesler et al, 2013). The rationale for this study was that most previous studies on transportation noise and children's health effects are on aircraft noise in schools, such as those described in this report. This study looked at road traffic noise at home in relation to behavioural problems and sleep disturbance.
- 3.25 Over 850 10-year old children from Munich participated. Noise levels at home as measured by L_{den} and L_{night} and behavioural problems were included in the study as assessed by the Strengths and Difficulties Questionnaire (SDQ). Briefly, the results suggested that noise exposure at the most exposed façade of the home was related to increased hyperactivity and noise at the least exposed façade of the building increased the chance for having borderline abnormal values on the emotional symptoms scale. The average value for the most exposed façade 52.4 dBA L_{den} , and the least exposed was 44.9 dBA L_{den} . At night this was 43.3 and 35.9 dBA L_{night} respectively. Night-time noise at the least exposed façade was associated with sleeping problems particularly in the ability to fall asleep in a sub-group of the study population for which this data was available. However, there was no significant association with the most exposed façade, suggesting confounding factors not addressed.
- 3.26 At the International Commission on Biological Effects of Noise (ICBEN) Congress in 2014, Charlotte Clark from Queen Mary University, London presented a study that was a further examination of the RANCH data and looked at teachers' reactions to environmental noise at school as a potential mechanism for noise effects on children's cognition.

- 3.27 Some of the mechanisms that have been suggested to account for how environmental noise may affect children's cognition include communication problems, teacher stress responses, learned helplessness, noise annoyance and frustration. The results of the RANCH study have been much reported elsewhere, (briefly that chronic noise exposure is associated with poorer reading comprehension and memory than non-noise exposed children) but this study focussed on the contribution of teachers' reactions to road and aircraft noise, and possible interaction with the children's learning outcomes.
- 3.28 Teachers in the RANCH study completed a questionnaire containing standardised measures of noise annoyance and perceived stress, as well as questions designed to assess perceptions of how they felt noise interfered with children's learning and performance. The five point ISO question was used to evaluate annoyance, and frequency of noise (road and aircraft) was assessed with a four point scale. The 10-item Perceived Stress Scale which assesses self-reported stress levels over the past month was also administered, along with questions relating to communication, student performance, quality of work etc.
- 3.29 270 teachers completed the questionnaires, and those exposed to aircraft noise at school were significantly more likely to report being moderately, very or extremely annoyed by aircraft noise at school than those teachers not exposed to aircraft noise at school. A similar association was found with traffic noise. Aircraft and road traffic noise were not associated with self-reported perceived stress, but teachers exposed to aircraft noise at school felt it significantly interfered with pupils' communication, concentration, performance, and quality of work. Similar associations were observed for road traffic noise. It is proposed that future analyses will explore these data as mechanisms for noise effects on children's learning within the RANCH project.
- 3.30 The European Network of Noise and Health (ENNAH) is discussed in detail in Chapter 6 of this report. As part of its work package on confounding and effect modifying factors, members were asked to draw causal diagrams for various effects and outcomes, to include potential confounders or moderating effects. Figure 5 shows the diagram produced for the causal pathways between aircraft noise and road noise and children's learning outcomes.
- 3.31 Although such diagrams are a useful tool for stimulating discussion and broad thinking about potential confounders and causal pathways, due to conflicting evidence it is not possible to draw conclusions. The group therefore suggest that the study of interactions should be given a high priority in future research into environmental noise and health. As part of this work package the RANCH study data was analysed further. Interestingly, air pollution was not found to be related to children's health and cognition in this study, and effects persisted even after air pollution was controlled for. In the HYENA study, which was also analysed further by this group, the aircraft noise $L_{eq16hour}$ distribution by country showed

higher exposures for the UK and the Netherlands than for Sweden, whereas the road traffic noise $L_{eq24hour}$ distribution was similar for the three countries. For NO_2 , there are quite considerable differences between the countries with no overlap between the UK and Swedish data despite the similarities in road traffic noise distribution.

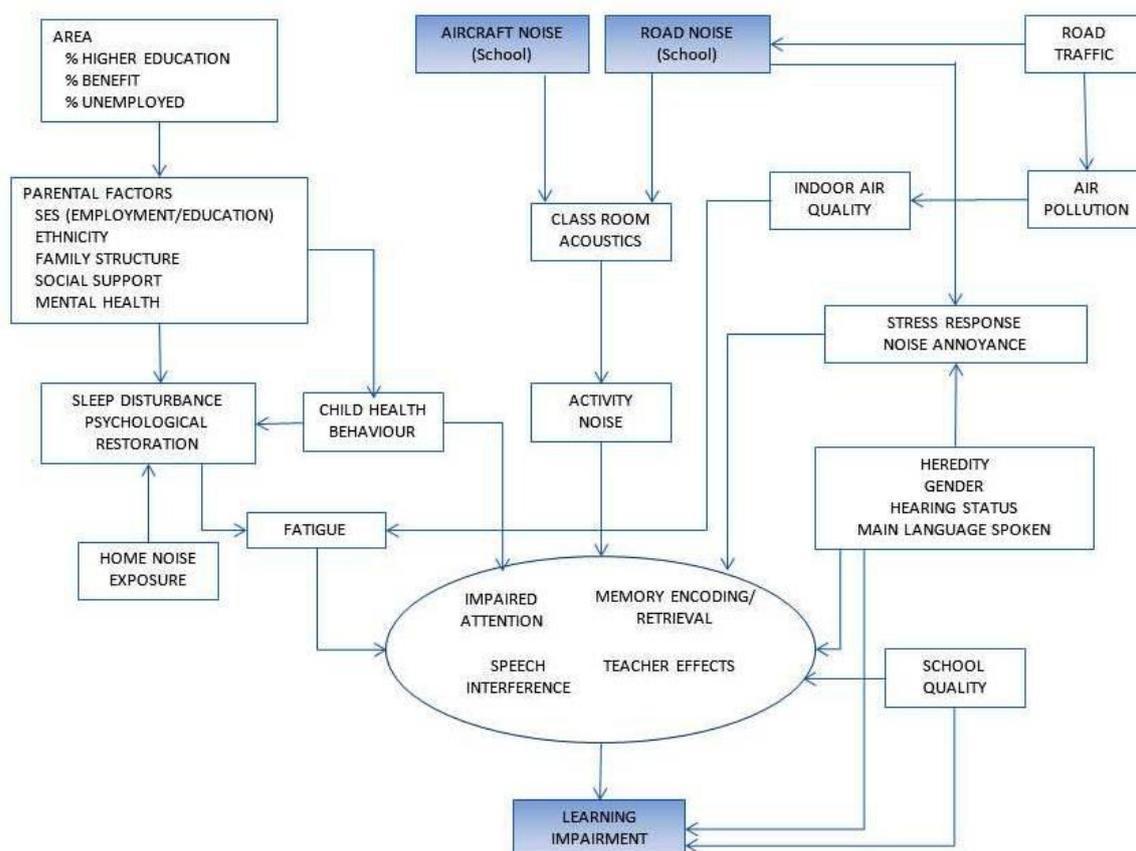


Figure 5: Association between road traffic and aircraft noise and learning impairment (taken from the ENNAH final report, 2013).

- 3.32 In late 2015 the initial results of the NORAH study were published. A description of the study can be found in Chapter 1 of this report. One of the work packages in this study investigated the effect of aircraft noise on children's cognition. Over 1200 primary school children were recruited from outside the 40 dBA L_{eq} envelope of daytime aircraft noise, and the schools were banded according to their noise exposure (40 – 45 dBA; 45 – 50 dBA; 50 – 55 dBA and > 55 dBA), with 7 or 8 schools in each category.
- 3.33 Reading ability, long-term memory, non-verbal abilities, attention, speech perception, verbal short-term memory and phonological awareness were assessed. Variables known to affect reading acquisition such as teachers' methods of reading instruction, children's SES and language spoken at home were assessed via teacher and parent questionnaires. In addition to cognitive

tasks, children's quality of life was assessed via standardised interviews of the children and parent questionnaires.

- 3.34 The findings of the NORAH study for children's learning reflected a small but significant decrease in reading performance equivalent to a one month reading delay, with an increase in aircraft noise levels of 10 dB LA_{eq}. One theory behind the way in which aircraft noise may impact on children's reading ability is that the noise interferes with pre-cursor skills, which children develop prior to school age. Such skills allow for the identification of sounds and good comprehension and listening skills. The researchers investigated these and found no significant effects of aircraft noise in relation to memory and phonological processing. To put the magnitude of the observed effect into perspective, the researchers stated that children who read at home are four months ahead in terms of reading texts compared to those who do not own their own books. This suggests that perhaps greater emphasis should be put on parents helping and encouraging children to read at home for increased progress with reading ability, than on the relatively small negative effect observed in relation to aircraft noise.
- 3.35 In terms of QoL, the authors reported that in general, all of the children studies exhibited a high level of QoL and they felt very well, healthy and enjoyed going to school. However, children exposed to higher aircraft noise levels reported symptoms such as headaches and stomach aches more often than those children who live in quieter areas. Parents in higher noise areas also reported that their child was taking prescribed medication or had been diagnosed with a speech or language disorder.

Chapter 4

Sleep disturbance and night noise effects

- 4.1 In January 2013, the CAA [ERCD Report 1208](#) was published, entitled 'Aircraft Noise, Sleep Disturbance and Health Effects: A Review'. This report provided an overview of the main findings within environmental noise at night and health research from the 1970s to 2013, and included the effects of sleep disturbance due to aircraft noise. The cost-benefit analysis of night flights was also discussed in terms of previous methodology and proposals for future evaluation of the aircraft movements at night were suggested.
- 4.2 This report covered the main effects of nocturnal environmental noise, such as cardiovascular disease, sleep disturbance and next day effects, and the impacts on children. It is not the intention to replicate ERCD 1208 in this report, as it already provides a thorough description of night noise effects and economic analysis methodology as it stands. Instead, this section will focus on the research that has been published since that report, from 2012 to the present day.
- 4.3 Hume et al (2012) published a review of the effects of environmental noise on sleep. This review highlighted the current state of knowledge and suggestions for future research directions. The current knowledge includes evidence for autonomic responses to low noise levels that do not result in awakenings, sleep stage changes, movement and brief wakefulness which can be associated with limb and body movement, the association between night noise and cardiovascular disease and that autonomic arousals habituate less in response to noise than cortical arousals. The authors suggest that the evidence does lack a causal pathway that directly links noise, sleep disturbance and cardiovascular disease. This could be addressed by a large scale longitudinal study that would measure noise-induced sleep disturbance and follows participants over several years but this would clearly be expensive and the results would take a long time to achieve.
- 4.4 An important consideration in studying noise-induced sleep disturbance is the presence of naturally occurring awakenings. We all experience spontaneous awakenings during the course of a normal night's sleep and we usually do not remember them, nor do they cause deleterious effects on alertness or next day performance. The challenge for noise and sleep researchers is to differentiate the naturally occurring spontaneous awakenings from those induced by noise. Previous research in 2011 on single and combined road, rail and aircraft noise exposures found that most (>90%) of the noise induced awakenings merely replaced awakenings that would have occurred spontaneously, and helped to preserve sleep continuity and structure despite the noise. The authors state that

this suggests that within limits there is some homeostatic mechanism for internal monitoring and control of waking arousals (or maintaining sleep) that are allowed during each night's sleep.

- 4.5 The review describes the requirement for continued research into the area of transportation noise and sleep disturbance and other health effects and cites the predictions from the International Civil Aviation Organisation (ICAO) Environment Report (2010) which reports that in 2006 the global population exposed to aircraft noise with 55 LDN or above was approximately 21 million people. This is expected to increase at a rate of 0.7 to 1.6% per year, while passenger traffic is expected to grow at an average rate of 4.8% per year until the year 2036.
- 4.6 The WHO Night Noise Guidelines (NNG) (2009) and the WHO Burden of Disease Report (2011) are briefly referred to in the review, both of which are described in ERCD Report 1208. To recap, the NNG summarise the relationship between night noise and health effects into four ranges of continuous outside sound level at night (L_{night}):
- <30 dB - Although individual sensitivities and circumstances differ, it appears that up to this level no substantial biological effects are observed.
 - 30-40 dB - A number of effects on sleep are observed from this range: Body movements, awakening, self-reported sleep disturbance, and arousals. The intensity of the effect depends on the nature of the source and the number of events. Vulnerable groups (e.g., children, the chronically ill and the elderly) are more susceptible. However, even in the worst cases the effects seem modest.
 - 40-55 dB - Adverse health effects are observed among the exposed population. Many people have to adapt their lives to cope with the noise at night. Vulnerable groups are more severely affected.
 - >55 dB - The situation is considered increasingly dangerous for public health. Adverse health effects occur frequently, a sizeable proportion of the population is highly annoyed and sleep disturbed. There is evidence that the risk of cardiovascular disease increases
- 4.7 WHO's view is that above 55 dB L_{night} noise is a significant concern to public health. As a result it has set an interim target of 55 dB $L_{\text{night, outside}}$. For the longer term it recommends that night noise exposure should be reduced below 40 dB $L_{\text{night, outside}}$. It is explained that the interim target is recommended in the situations where the achievement of the NNG is not feasible in the short-term for various reasons. With present technology, achievement of the 40 dB L_{night} target would require almost complete closure of all transport systems, including roads, railways and airports. The interim target is not a health-based limit value by itself and vulnerable groups cannot be protected at this level.

- 4.8 The WHO Burden of Disease report suggests that sleep disturbance, due mainly to road traffic noise, constitutes the heaviest burden followed by annoyance which account for 903 000 and 587 000 DALYs, respectively. The other factors associated with environmental noise are ischemic heart disease (61 000 DALYs), cognitive impairment in children (45 000 DALYs) and tinnitus (22 000 DALYs). The report concludes with the estimate that at least one million healthy life years are lost every year from traffic related noise in Western Europe.
- 4.9 Perron et al (2012) also conducted a review of the effect of aircraft noise on sleep disturbance. This review included many of the papers discussed in ERCD 1208 and only included research that was published until 2010. All moderate-to high-quality studies of the twelve reviewed showed a link between aircraft noise events and sleep disturbances such as awakenings, decreased slow wave sleep time or the use of sleep medication.
- 4.10 The authors identified several gaps in current knowledge that need to be addressed. There is a void of studies examining the effects of aircraft noise on the sleep of older people and those with chronic illnesses and pre-existing sleep disorders. Parameters such as total sleep time, awakenings, Slow Wave Sleep (SWS) time, and Rapid Eye Movement (REM) stage sleep time should all be investigated in these groups. There is a need to further understand the role of annoyance in sleep disturbance and how this is characterised. It is also suggested that the influence of background noise should be examined on aircraft noise effects.
- 4.11 Fidell et al (2013) from the USA published their research on aircraft noise-induced awakenings and types of sound exposure. The paper discusses the problems surrounding the use of absolute indoor sound exposure levels (SEL) to predict aircraft noise-induced awakenings. The authors refer to the American National Standards Institute publication (ANSI, 2008) which identifies two methods of measuring noise-induced awakening. The first method predicts the probability that an individual noise event will awaken a person as a result of its SEL alone. The second method predicts the probability that an entire distribution of aircraft noise intrusions over the course of a night will awaken a person at least once (or multiple times). These methods are examined by Fidell et al and it is explained that the statistical reasoning on which the second method is based relies heavily on the analysis of the first method and a strong assumption of complete independence of awakenings from one another throughout the night.
- 4.12 The authors argue that these methods do not take into consideration the role that habituation may play in the likelihood of aircraft noise-induced awakenings. They present evidence for different awakening rates at similar noise exposure levels at different airports, described as adaptation level theory. This hypothesis is that noise events that deviate from community expectations following habituation to familiar night-time noise environments are more likely to awaken residents than

those which conform to their expectations about night time noise. Further evidence for the role of habituation is that the probability of awakening seems to be more closely tied to the standard deviate of a noise event's SEL at a particular airport rather than the absolute value. The odds ratios of awakening due to individual noise events do not seem to be closely related to absolute sound levels. Finally, the probability of awakening due to road noise or aircraft noise seems to be source-specific.

- 4.13 The authors conclude that the current state of knowledge for predicting aircraft noise-induced awakenings using absolute indoor SELs falls somewhat short and there is uncertainty surrounding the methods. Of particular importance is the need for habituation to be factored in to methods recommended for the prediction of aircraft noise-induced awakenings.
- 4.14 Boes et al (2013) reported their results on aircraft noise, health and residential sorting. The authors explain the limitations of using cross-sectional experimental data and the reason why evidence from such studies cannot be given a casual interpretation. This is because individuals are not randomly exposed to noise and neighbourhoods differ in other characteristics other than noise, such as quality of the area. In addition, people may self-select into areas based on their preferences for quietness, pre-existing health conditions, and their ability to afford to live in a quiet neighbourhood. This inevitably leads noise-sensitive people to live in quiet areas, and noise-insensitive and resistant people to live in noisier and often more affordable areas. Boes et al use fixed effects models, (statistical models that represent the observed quantities in terms of explanatory variables that are treated as if the quantities were non-random), to control for time-constant confounders, including both unobserved individual heterogeneity and spatial sorting into different neighbourhoods related to health.
- 4.15 The study took advantage of two changes in operations at Zurich airport, the first being the closure of the east/west runway for two months in summer 2000 due to a new terminal building being constructed. During this period, aircraft used the north/south runway instead of the east/west one. The second large-scale change was in 2003 when the German government prohibited landings over their territory in the early morning and in the late evening as a protective measure against noise pollution. After a temporary redistribution of incoming flights to the east, the Swiss Federal Office of Civil Aviation changed the flight regulations to allow for landings from the south, which had been previously prohibited.
- 4.16 After this change which started in October 2003, early morning aircraft were redirected to land from the south and late evening aircraft from the east. Self-reported health data was used from the Swiss Household Panel (SHP) which is collected annually from 5,000 members of the Swiss population. The researchers looked at subjective health outcomes that were likely to be impacted by aircraft noise such as sleep quality, headaches, 'weakness/weariness', and measures of

general health such as the number of doctor consultations and days affected by health issues. Each person in the SHP was linked to detailed continuous and longitudinal aircraft data based on their address.

- 4.17 Interestingly, the researchers suggest that cross-sectional study designs and analysis of aircraft noise and health effects probably underestimate the effects. It is explained that in such cross-sectional studies the association between aircraft noise and health is often insignificant or very small, but once individual fixed effects are included, aircraft noise is found to significantly increase sleeping problems and headaches. A possible reason for this difference is that noise sensitive people will self-select to live in quieter areas and therefore the population there is negatively linked with respect to pre-existing health inputs. It is suggested that those studies that do not control for such type of sorting will consequently underestimate the causal effect of noise on health. Individual fixed effects used in this study control for noise sensitivity, which is a stable trait that is independent of observed noise levels.
- 4.18 A further explanation is the presence of habituation to noise. If this process occurs slowly, the underestimation of noise effects due to habituation will be smaller in fixed effects models than in cross-sectional models. In addition, avoidance behaviour could also influence the results, such as closing windows at night, and soundproofing. The authors suggest that this methodology using fixed effects is a powerful way of identifying causal effects in epidemiological field studies such as those employed in noise and health research.
- 4.19 In 2013 a Partnership for AiR Transportation Noise and Emissions Reduction (PARTNER) report in collaboration with FAA, NASA and Transport Canada, authored by McGuire and Davies was published on the various ways to model aircraft noise-induced sleep disturbance. The report discusses the use of previously developed models, which generally predict the percentage of the population that is awakened. Other models such as Markov state and nonlinear models have been used to predict individual sleep structure throughout the night.
- 4.20 The report explains the limitations of such models, for example the Markov model only allows for whether an aircraft noise event occurred and does not take account of the noise level or other sound factors which may influence the amount of disturbance. The nonlinear dynamic models were developed to describe normal sleep regulation and do not have a noise effects component. In addition, the nonlinear dynamic models have slow dynamics which make it difficult to predict short duration awakenings which occur both spontaneously and as a result of night-time noise exposure.
- 4.21 The report discusses the ways in which the models can be improved to more accurately predict the effects of aircraft noise on sleep and then comparisons are made between the results when tested on data from US flight operations data. The thesis is a highly detailed and complex report, and explores many

modifications of existing sleep models. In brief, a nonlinear dynamic model was developed by the authors that may be a possible tool for predicting sleep disturbance in communities if further refinements are made to it. The model was based on the 1999 UK sleep study data set, and it is explained that it also needs to be tested on other datasets for further validation.

- 4.22 One of the advantages of this type of model is that model coefficients can be related to specific physiological processes and the parameters of the nonlinear model can be estimated using data for each subject night. The authors explain that this may enable sleep disturbance to be predicted for a variety of subgroups within populations, such as the elderly, children and vulnerable groups who may have conditions that affect their sleep by estimating and using a different set of model parameters for each group.
- 4.23 Janssen et al (2014) examined the effect of number of aircraft noise events on sleep quality. The rationale for this study was that although WHO recommends the use of L_{night} as the primary indicator for sleep disturbance, there is some evidence to suggest that the number, characteristics and distribution of individual noise events throughout the night can impact sleep disturbance. The authors explain that the WHO NNG and the European Noise Directive (END) allow the use of both the maximum sound pressure level (L_{max}) and sound exposure level (SEL) in addition to L_{night} to predict sleep quality.
- 4.24 The aim of the study was to investigate whether L_{night} sufficiently represents the number of aircraft noise events that contribute towards prediction of sleep disturbance by motility, and the association between sleep quality and number of events. The second aim was to investigate whether the number of events at a given L_{night} has an additional predictive value. In addition, it was explored whether the total number of events should be taken into account for the production of sleep quality, or only the number of events exceeding a certain sound pressure level.
- 4.25 Data collection occurred around Schiphol airport between 1991 and 2001 from 419 residents at varying distances from the airport. The study lasted eleven days and participants were requested to complete morning and evening diaries, reaction time tests, sleepiness scales and wearing an actiwatch for the duration of the study. They were exposed to normal aircraft noise levels at home, all of which were within 20km of the airport, and selected on the basis of their L_{night} noise levels. Sleep quality was determined by self reported sleepiness and actigraphy, which also measured motility.
- 4.26 The results indicated that additional information on the overall number of events does not improve the prediction of sleep quality. The number of events of higher noise levels (> 60 dBA L_{max}) was associated with an increase in motility, which suggests a decrease in sleep quality. There was no effect of number on self-reported sleep quality. The authors suggested that the number of events is more

or less adequately represented by L_{night} and only the number of high noise level events may possibly have additional effects on sleep quality as measured by motility. It is proposed that in addition to L_{night} , the number of events with a relatively high LA_{max} could be used as a basis for protection against noise-induced sleep disturbance.

- 4.27 The sleep study results from the NORAH study were published in 2015. This study aimed to examine any changes in sleep quality and disturbance as a result of changes to the nocturnal volume of air traffic at Frankfurt Airport. In October 2011 night flying restrictions for scheduled flights were imposed from 2300 to 0500, with only delayed arrivals or departures being allowed as exceptions. Previously, between 50 and 60 flight movements were permitted between 2300 and 0500. In addition, a new runway was opened at the same time, which altered the patterns of aircraft noise around the airport.
- 4.28 Over 200 participants living around the airport had their sleep measured in their own homes by polysomnography for three times (three to four nights on each occasion). A sound recorder simultaneously recorded all noise inside of the bedroom, and the loudness. The first measurements were taken in summer 2011, prior to the change in night flying restrictions and the new North West runway was opened. The other measurements were taken in the summers of 2012 and 2013.
- 4.29 Participants were questioned about their usual sleep habits and were excluded if suffering from conditions such as sleep apnoea, allergies that required medication, or if the family had children under the age of six and therefore potentially had disturbed sleep, or shift workers. In addition, participants were required to have regular sleep patterns. The people who participated in 2011 usually went to bed between 2200 and 2230 hours and got up between 0600 and 0630. In 2012 and 2013 people also took part that went to bed and got up on average one hour later. This allowed for analysis of shoulder hour periods between 2200 and 2300 and 0500 and 0600. For the years 2011 and 2012 the measurements were recorded by polysomnography, and in 2013 the researchers used a new method called vegetative-motor method, which combines Electrocardiography (ECG) and body movements to determine awakenings. This method is less expensive and time consuming than traditional polysomnography, which requires multiple electrodes to be accurately attached to the participant.
- 4.30 The results are not yet available in English, but presentations of the work explained that findings indicated that there was no large difference in awakenings between 2011 and 2012, although the probability of awakenings was slightly higher in 2011. The main conclusions were that awakening frequency per night decreased from 2011 to 2012 from 2.0 to 0.8 for those participants who went to bed between 2200-2230. For participants who went to bed between 2300-2330 the frequency of awakening was 1.9 times per night,

suggesting that going to bed earlier acts as a protective measure against noise. Comparisons were made for total sleep time, sleep onset latency, sleep efficiency and time spent awake and it was found that the overall quantity and quality of the sleep did not change between 2011 and 2012. Interestingly, the findings suggested that participants who exhibit a more negative attitude to aircraft noise show more objectively measured sleep disturbances. It is possible that this is related to noise sensitivity in those particular individuals.

- 4.31 The study also measured self-reported sleep quality as part of the annoyance work package. The findings indicated that there was less self-reported sleep disturbance in 2012 compared to 2011 which is unsurprising given the night flight restrictions, but there was an increase in early morning sleep disturbance between the two years. This suggests that the night flight restrictions do not adequately protect against self-reported sleep disturbance in the early morning shoulder hours. More detailed findings from the NORAH study will be available once the results are published in English and it should not be assumed that this is a comprehensive review of the study.

Chapter 5

Other health effects

Nocturnal effects

- 5.1 Elmenhorst et al (2010) examined the effects of nocturnal aircraft noise in both laboratory and field studies on cognitive performance the following morning. The study of next day cognitive effects of night-time aircraft noise is rare and has previously shown inconsistent results, with some findings suggesting that the number of aircraft noise events is an important contributor to next-day effects, and others describe performance decrements related to the maximum SPL or LA_{eq} experienced during the previous night. Other studies have found no association between aircraft noise exposure and next-day cognitive performance.
- 5.2 This study was designed to include a large sample and a wide range of number of aircraft noise events per night, maximum SPLs and LA_{eqs} . The presence of both laboratory and field data also allows for direct comparisons in the data analysis from both settings. In the laboratory, 112 participants were exposed to aircraft noise during 9 consecutive nights. In the field, 64 participants were examined during 9 consecutive nights in the vicinity of Cologne/Bonn airport. Reaction time, signal detection performance and subjective task load were recorded.
- 5.3 The results indicated a significant association with aircraft noise LA_{eq} levels and impaired performance on the Psychomotor Vigilance Test (PVT) in the laboratory study ($p = 0.0014$). Mean reaction time in PVT was 241.0 ms (± 2.0 SE) under baseline conditions (day 2) and increased up to 245.9 ms (± 2.5 SE) at day 11. Reaction time improved immediately to 242.3 ms (± 2.8 SE) after one recovery night (day 12). The results from the field study indicated that one model including LA_{eq} and time in study yielded significant results. Mean reaction time increased with LA_{eq} ($p = 0.0284$) and with time in the study ($p = 0.0008$).
- 5.4 Interestingly, in the laboratory study reaction times on the Memory Search Task (MST) significantly decreased during the study under noise conditions ($p = 0.0083$), and increased again following one night of recovery sleep. However false alarm rates also increased along with faster reaction times over the course of the study. In the field study the time of the study was significantly associated with false alarm rates, with increased linearly and significantly from day to day ($p = 0.0046$). Mean reaction was not affected in the field.
- 5.5 There was a cumulative performance loss in both the laboratory and the field settings, with mean reaction time on the PVT increasing, and the probabilities for

lapses increasing in the laboratory study. Due to the recovery nights in the laboratory, the researchers could show that mean reaction time in PVT increased depending on the LA_{eq} level of the previous night, and immediately recovered after one night without noise. The authors suggest that observed changes in MST could hint at a change in working strategy which causes the participants to work faster but less accurately. That could be a consequence of nocturnal aircraft noise as well as a mere response to the repetitive nature of the task during the study.

- 5.6 The authors propose that the results hint at changes in physiological processes due to nocturnal aircraft noise exposure. Only healthy adults were included, however, the researchers infer that the effects of nocturnal aircraft noise may result in stronger impairment in vulnerable groups such as children or people who are ill.

Psychological factors and annoyance

- 5.7 Kroesen et al (2010) investigated the effects of psychological factors on aircraft noise annoyance in an attempt to determine the direction of causality. The study took place around Schiphol airport in Amsterdam with randomly sampled residents who were living within the 45 L_{den} contour around the airport. The data were gathered in two surveys conducted in the periods April 2006 ($n = 646$) and April 2008 ($n = 269$). The rationale for this study is that cross-sectional study methods are usually used to examine attitudes towards aircraft noise. In these cases, since the independent and dependent variables are measured at the same time, the time precedence (i.e. X comes before Y in time) cannot be fully investigated and as such the direction of causation remains uncertain. There is still the question of whether the investigated social-psychological factors cause aircraft noise annoyance, or vice versa. Natural experiments, such as the closure of a runway can counteract this, but those instances are rare.
- 5.8 In this study the aim was to determine the direction of causality between 13 social-psychological factors and noise reaction. A Structural Equation Model was estimated based on repeated measures panel data gathered from the residents. Using a panel model can provide experimental tests for the time precedence and also addresses the issue of chronological order. The authors chose this method with the aim of retaining both the advantage of a field study in terms of high external validity and the advantage of an experiment in terms of high internal validity.
- 5.9 The results indicated that that none of the paths from the psychological factors to aircraft noise annoyance are significant. However, surprisingly, two effects were found to be significant the other way around: (1) from 'aircraft noise annoyance' to 'concern about the negative health effects of noise' and (2) from 'aircraft noise

annoyance' to 'belief that noise can be prevented.' This means that aircraft noise measured at time 1 contained information that can effectively explain changes in these two variables at time 2, whilst controlling for their previous values. Secondary results also show that aircraft noise annoyance is very stable through time and that change in aircraft noise annoyance and the identified psychological factors are correlated.

- 5.10 The authors suggest that the direction of causality between aircraft noise annoyance and possible social-psychological factors is important for noise policy as the policies aimed at these factors can only be effective if the direction of causality is confirmed to be from such factors to aircraft noise annoyance. They propose that if, for example, personality traits can be found to be dominant in the explanation of individual differences, then more individually tailored noise policies would be preferable.

Noise and pregnancy

- 5.11 Hohmann et al (2013) reviewed the literature on chronic noise exposure and health effects during pregnancy and early childhood. The effects of noise on children are reviewed in Chapter 2 of this report, so this section will report only the findings during pregnancy. Twelve papers on pregnancy/birth outcomes were included, with samples ranging from 115 to 22,761. The papers focussed mainly on occupational noise, but have been included in this report due to a lack of research into aircraft noise specific effects on pregnancy. The aim was to evaluate studies on the association between chronic noise exposure during pregnancy and birth outcomes and the health of foetuses and infants (birth outcomes).
- 5.12 Six pregnancy cohort studies and four case-control studies examined birth outcomes and looked at occupational noise. One study additionally assessed environmental noise exposure and two cross-sectional studies examined the impact of chronic aircraft noise.
- 5.13 The results of the review indicated that chronic occupational noise exposure did not seem to be associated with birth weight of newborns, congenital abnormalities and pre-term foetal growth. The results on aircraft noise exposure and birth weight was inconclusive, with one of the studies (Schell et al, 1981) reporting a non-significant partial correlation between aircraft noise and gestational length. The other study by Knipschild (1981) found a significant negative association between aircraft noise and birth weight between non-exposed women and those exposed to 65–75 dB LA_{eq} (day/night).
- 5.14 The authors explain that due to the limited quality of most studies and a high variation in exposure and outcome assessments, final conclusions on the

association between chronic noise exposure and paediatric outcomes cannot be drawn. They suggest that future studies should examine different noise sources, locations and time of day, considering the noise exposure at each location. Information on subjective noise annoyance and noise sensitivity should also be collected by self-report in addition to objective assessments. There is a particular need for high quality long-term prospective studies on the impact of chronic noise exposure on paediatric outcomes with more advanced outcome-exposure assessment and strong analysis strategies. Attention also needs to be given to potential confounders such as opening/closing of windows, insulation and duration of noise measurement in any future studies.

- 5.15 Ristovska et al (2014) also published a review of reproductive outcomes associated with noise exposure. This review included much research on occupational noise, but there were some epidemiological studies that examined aircraft noise and birth outcomes. A study from Japan (Matsui et al, 2003) found significant risk for low birth weight for mothers exposed to aircraft noise above 85 dBA. Another large population base cohort study from Canada (Gehring et al, 2014) found adverse effects of road traffic noise exposure and for all transportation noise associated with term birth weight and term very low birth weight. The noise effect on term birth weight was largely unchanged after adjustment for air pollution. Two smaller studies with lower quality scores also saw higher risk of low birth weight with higher noise exposure. A further two studies investigated correlations not risks, finding associations with birth weight in female but not male babies (Schell, 1981) or no association with low birth weight (Wu, 1996).
- 5.16 The authors explain that there is therefore supporting evidence for associations between low birth weight and noise exposure including from the better designed and larger occupational and epidemiologic studies, although they caution that associations were not consistently found across all studies and the total number of studies to date is small. Findings and conclusions for low birth weight differ with conclusions of Hohmann's review because this review included one large population based cohort study published after the Hohmann review, one large study from Japan and one case control study from China which were not included in that previous systematic review. These three studies gave supportive evidence for association between higher level of noise exposure and low birth weight.
- 5.17 The authors explain that there is a need for more research into environmental noise exposure and reproductive outcomes, and make the following recommendations for future research:
- objective and well-designed environmental noise exposure assessment;
 - well-designed epidemiological studies;

- adjustment for confounding factors, such as life-style factors (smoking, alcohol use, drug use);
- characteristics of parents (parental weight and height, mother's age, race, ethnicity);
- socioeconomic status and pregnancy history for spontaneous abortion;
- congenital malformations;
- adjustment for air pollution when considering outdoor transportation noise; and
- standardised outcome definitions including use of birth weight < 2500 g for low birth weight, preferably with information on gestational age and birth less than 37 completed gestational weeks for preterm birth, in order to obtain comparable results.

Obesity

- 5.18 In 2014 a Swedish study by Eriksson et al was published that claimed a link between aircraft noise and obesity. The study was part of the longitudinal study on hypertension (Eriksson, 2010) and aimed to investigate effects of long-term (up to 10 years) aircraft noise exposure on body mass index (BMI), waist circumference, and Type 2 diabetes in over 5000 residents in Stockholm County.
- 5.19 The main finding was that there was an association between aircraft noise exposure and increased waist circumference after adjustment for individual and area-level confounders. The mean increases in BMI and waist circumference during follow-up were $1.09 \text{ kg/m}^2 \pm 1.97$ and $4.39 \text{ cm} \pm 6.39$, respectively. The cumulative incidence of pre-diabetes and Type 2 diabetes was 8% and 3%, respectively. Based on an ordinal noise variable, a 5-dBA increase in aircraft noise was associated with a greater increase in waist circumference of 1.51 cm; 95% CI: 1.13, 1.89; fully adjusted.
- 5.20 The authors found that this association appeared particularly strong among those who did not change their home address during the study period, which may be a result of lower exposure misclassification. However, no clear associations were found for BMI or Type 2 diabetes. In addition, sleep disturbances did not appear to modify the associations with aircraft noise.
- 5.21 Although this study attracted media attention due to the public interest angle, there are several limitations that must be taken into account when interpreting the results. Firstly, the study has a narrow range of exposure and a small number of highly exposed cases. This was particularly evident for Type 2 diabetes where only 47 cases had ever been exposed to aircraft noise, and only

26 cases exposed at ≥ 50 dBA. Therefore, the associations between aircraft noise and pre-diabetes and Type 2 diabetes in this study are uncertain.

- 5.22 A further important limitation is the lack of objective data on exposure to noise from other sources, such as road traffic, railways, and occupation, which may be potential confounders. Another major issue with this study is the over-sampling of people with a family history of diabetes (50% compared to the average of 20-25% in the general population). The authors explain that although there was no significant difference found in the effects of noise exposure in those people with a family history of diabetes compared to those without, the associations between aircraft noise and BMI as well as waist circumference appeared stronger among those without family history of diabetes. It is cautioned that this could influence the possibility of generalising the finding to the population as a whole.
- 5.23 Two papers were presented at the ICBEN Congress in 2014 that also investigated the possible links between environmental noise obesity. Bente Oftedal from the Norwegian Institute of Public Health presented a paper on research into the association between exposure to road traffic noise and markers of obesity. The study used data from 2000 and 2001 from 15,000 participants who had measurements of weight, height, waist circumference and waist-hip ratios taken.
- 5.24 Road traffic noise was modelled (L_{den}) at the most exposed façade of each of the participants' addresses, and regression modelling was used to analyse the associations between road traffic noise and obesity markers. The researchers were particularly interested in noise sensitivity as a potential modifying factor, and the genders were analysed separately. The results indicated that there were no associations between road traffic noise and obesity markers in women or men. There was a significant interaction between noise level and noise sensitivity in women, but not in men. Road traffic noise levels was positively associated with waist circumference and body mass index in the highly noise sensitive women, but this was not found in men. The researchers suggested that noise sensitivity is an effect modifier in the association between noise and risk of obesity in women. This is an interesting area of research, and has not yet been studied with respect to aircraft noise.
- 5.25 A co-author of that study, Goran Pershagen from the Karolinska Institute in Stockholm presented a paper at ICBEN on traffic noise and central obesity that included over 5000 participants living in Stockholm during 2002-2006 (same epidemiological data as Eriksson, 2010). This study included different noise sources; road, rail and aircraft noise at residential addresses (obtained from geographical co-ordinates and digital noise maps) and examined the individual noise sources, and combined effects.
- 5.26 The data was analysed using logistic and linear regression with adjustment for possible confounding factors. Statistically significant associations between traffic

noise and waist circumference were found, with a 0.3cm increase per 5 dBA L_{den} for road traffic, 0.6cm for railway noise and 1.0cm for aircraft noise. When the combined exposures were examined, a noise level above 45 dBA was associated with an odds ratio for obesity of 1.9, and similar patterns for waist-hip ratio but there were no associations found for body mass index.

- 5.27 The authors suggest that noise may act as a stressor and lead to the increased production of cortisol and other stress reactions. Elevated cortisol levels can result in the storage of fat in reserves within organs, and thus contribute to central obesity rather than generalised obesity. This stress theory echoes that of Babisch's general stress theory for noise-induced health effects. The authors also propose that central obesity may be a potential mediator of noise effects on the development of cardiovascular diseases and diabetes and there is a particularly strong association with aircraft noise and central obesity and for those people who are exposed to multiple traffic noise sources.

Chapter 6

European Network of Noise and Health

- 6.1 The European Network of Noise and Health (ENNAH) was set up in 2009 and is the largest network ever established in this research area, comprising academic researchers and health workers throughout Europe. In total, 33 partners from 16 countries were part of this network.
- 6.2 The outcomes of this project serve to identify gaps in the current research on noise and health, and provide suggestions for the prioritisation of future directions in this field. An example of these is the inclusion of air pollution confounding variables in noise and health research, in particular for environmental noise and transportation noise studies where there is inevitably a level of air pollution as a result of the noise sources themselves, as well as supplementary sources.
- 6.3 The ENNAH network has provided opportunities for young researchers throughout Europe to collaborate across countries and work together. This is important for the future of research in noise and health and helps to gain consistency with approaches across Europe. In addition to this ENNAH has provided a valuable contribution to the noise burden of disease calculations for Europe.
- 6.4 Recommendations for future noise and health research included the need to strengthen existing relationships with the use of longitudinal studies to assess the long-term impacts of acute noise exposure. Increased research into noise intervention policies and their effectiveness in terms of health impacts and cost was also suggested as a future direction, together with a detailed assessment of future investment areas that would be most important to enhance current knowledge
- 6.5 The ENNAH project ran for two years, and had the following objectives:
- To review existing literature on noise and health with consolidation of existing knowledge and the identification of research gaps.
 - Ensure most recent measures of noise exposure assessment are applied to health studies.
 - Assessment of moderating factors such as air pollution and its joint effect with noise.
 - Enhanced communication between researchers in the two areas (noise and air quality).

- Development of new designs for research on noise and health and to provide EU with new strategies.
- The set-up of an exchange programme for young researchers.
- Dissemination of results to a range of audiences.

6.6 The structure of the network was organised into work packages, with work package 1 being the management of the network, and led by Stephen Stansfeld, Queen Mary University of London. The main findings from the other work packages are summarised below.

Work package 2: Review of evidence

6.7 This work package was led by Anna Hansell of Imperial College, London. The main aim of this group was to conduct a thorough literature search on a broad spectrum of areas relating to noise. These included physiological, psychological and psychosocial effects of environmental noise. After consultation with the other work package members, the most relevant studies were included and ranked according to agreed criteria.

6.8 Several gaps in the literature were identified, including:

- the effect of combined sources (many reviews describe the effect of a particular noise source, but the combined effects of more than one source are not yet understood);
- changing noise characteristics (for example the effect of tone on annoyance);
- mechanisms of co-exposures;
- noise sensitivity;
- definition of vulnerable groups;
- distinction between short and long-term effects;
- the relationship between sleep disturbance and stress;
- the role of annoyance in health outcomes;
- the role of noise in social behaviour;
- habituation to noise.

Work package 3: Noise exposure assessment

- 6.9 This work package was led by Danny Houthuijs from the National Institute for Public Health and the Environment in the Netherlands. The main objectives of this stream of the project were to discuss the current practice of noise exposure measurement and of strategic noise mapping in Europe and its potential use of health studies, and to identify novel methods and advanced measurement techniques for noise exposure assessment in future studies.
- 6.10 Since the END required strategic noise maps and action plans to be produced in order to gain information relating to major roads, railways and airports in agglomerations for the year 2006, approaches and techniques to noise modelling and measurement have improved. As a result of the required noise maps, a large amount of information is now available that is of use in environmental noise and health research but it is considered important to examine the exposure indicators to enable valid assessments of noise exposures in relation to noise and health outcomes.
- 6.11 Some of the lessons learned from EU noise mapping include general issues such as the definition of agglomerations, relevant year and quality of data. It was suggested that in order to achieve a fair comparison between EU countries and a further insight into noise and health, in terms of modelling, noise exposure assessment in health studies requires higher quality mapping beyond that of END requirements. GIS data sets are a possibility for linking noise to health outcomes due to the large data sets.
- 6.12 One of the suggestions from this work package is the use of 35dB during the night and 45dB during the day for road noise to increase contrast in exposure for health studies. It is important to note, however, that this is very difficult to achieve for any noise source as the background noise will often exceed these levels, especially in urban areas, making it very challenging to separate the aircraft or other transport noise from ambient levels. Another suggestion from this work package is that individual levels rather than 5dB contour bands should be available and vice versa. In health studies cut-off values should be introduced at the lower end.
- 6.13 In addition it was recommended that noise assessment should be increased to other facades as well as the most exposed. In terms of metrics it was proposed that L_{den} and L_{night} may not be the most relevant descriptors for health research. There is a need for a broader variety of indicators such as L_{eq} for health endpoints or event characteristics, for example L_{max} , SEL, Number Above and Time Above.
- 6.14 Exposure indicators should consider the critical time window and location of exposure. For sleep, exposure measurements should be taken in the bedroom

for the duration of the sleeping period. Although this is a valid suggestion in theory, in practical terms this is again very difficult to achieve and control for other noise sources and background levels.

- 6.15 The recommendation was made that cumulative noise exposure should be taken into account for health studies, such as years of residence and change in residence and/or in exposure. This is relevant, given findings from Hansell (2013), which suggested that length of residency is an important factor in the link between aircraft noise and cardiovascular disease.

Work package 4: Confounding and effect modifying factors

- 6.16 This work package was led by Goran Pershagen from the Karolinska Institute, Stockholm. This group had several aims. Firstly, to identify potentially important confounders/effect modifiers in studies on noise effects on health including air pollution and individual susceptibility factors such as lifestyle/environment and genetic factors. Secondly to propose strategies for the assessment, analysis and interpretation of the role of such factors in health-related noise research. The development of collaborative working relationships between researchers in areas relevant to the field was a further aim, as was the need to perform further analyses of the HYENA and RANCH data.
- 6.17 In addition to air pollution, confounders to cardiovascular effects of environmental noise include age, gender, SES, ethnicity, smoking, alcohol, weight and physical activity. Potential additional confounders are heredity, diet, hormones, noise from other sources and shift work. The group therefore suggest that the study of interactions should be given a high priority in future research into environmental noise and health.
- 6.18 This work package concluded that for cognitive outcomes, socioeconomic status is crucial to take into account. Coping factors and psychological restoration may also be important in this area of research. For cardiovascular outcomes, socioeconomic factors are generally important to consider but in both cases socioeconomic classification should consider individual and contextual confounding variables.

Work packages 5a and 5b: Measurements of health outcomes in epidemiological studies and European Health Impact Assessment

- 6.19 ENNAH's work package 5a was led by Francesco Forastiere of the Department of Epidemiology, Lazio Regional Health Service (Italy) and had three main aims:

- To discuss the improvement of the measurement of health outcomes relevant to noise research
 - To get consensus on standardised methodologies to be used in future studies on health effects of noise
 - To make recommendations for further research.
- 6.20 It was suggested that the instruments used to measure outcomes as a result of environmental noise should be specifically tailored according to the age group of the target population i.e. infants, children, adolescents, adults, and the elderly.
- 6.21 The emerging areas of research identified for specific age ranges were narrowed down to:
- Children – perinatal disorders, growth hormones, puberty, sleep disorders
 - Adults – fertility, reproductive disorders, diabetes secondary hypertension
 - Elderly – diabetes, transient ischemic attack, stroke
- 6.22 This group also suggest that the biological mechanisms of noise-induced health effects should be postulated before including a noise related health outcome. In practice, of course this may not always be possible as the causal pathways are not always fully understood due to the various possibilities of outcome.
- 6.23 It was highlighted that it is important to give due consideration to recall bias when analysing self-reported health or wellbeing responses, compared to the complexity of measurement-based research, which may result in a potentially lower response rate. Laboratory studies are important but this group suggests that field studies are essential in order to establish realistic conditions. In addition, it is recommended that more research is needed on the long term effects of noise.
- 6.24 New biological indicators proposed by this work package include prolactin (a secondary stress hormone), blood lipids, inflammatory markers and serotonin.
- 6.25 Work package 5b was led by Nino Kuenzli from the Swiss Tropical and Public Health Institute, with the aim to discuss methods for Health Impact Assessment (HIA) in Europe.
- 6.26 There is an existing framework for the calculations of Disability Adjusted Life Years (DALYs) for annoyance, sleep disturbance, and cardiovascular effects, but as annoyance is the largest burden, it was proposed that there is a need to incorporate more meaningful aggregated measures of health into the HIA, such as well-being and cardiovascular factors. DALYs are highly sensitive to the disability weighting attributed to them. This is important as it could potentially influence the outcomes of non-direct health impacts such as sleep disturbance and annoyance, both of which make up the largest proportion of burden in noise

HIAs so far. Caution is advised when evaluating the total burden from different health endpoints also, as there is potential for double-counting. Due to these issues, the work package recommends the development of more integrative objective and subjective quality of life outcomes. In addition it is recommended that vulnerable groups need consideration as part of the HIA process.

- 6.27 The work stream group also considered that the evaluation of impacts for different socio-economic groups, to take into account setting-specific co-exposures and environmental factors, is of special importance for future research.

Work package 6: New strategies for noise and health research in Europe

- 6.28 This work package was led by Stephen Stansfeld of Queen Mary University of London with the aim of developing new strategies for noise and health research as the primary outcome of the ENNAH project and considered current research challenges as well as future directions for this field.
- 6.29 Current research challenges include the need for refinement in estimated dose-response relationships for cardiovascular endpoints. Only disease specific morbidity and mortality is recommended to be included, as well as disease specific confounders in analyses. It is also recommended to prioritise clinical measurements over questionnaires, although standardised and validated versions of these should also be continued to be used. The group suggests that research emphasis should be on strengthening and updating the dose-response relationships for classical cardiovascular endpoints and environmental noise. It is further recommended that Ischaemic Heart Disease (IHD) (or coronary heart disease) should include myocardial infarction and hypertension with stroke as a new end point.
- 6.30 The importance of considering differences in day and night time noise exposure was discussed in this work package and there is the suggestion of possibly measuring noise levels inside the bedroom. As previously mentioned, practically this would be very difficult to control for as there would be such a range of individual differences in background noise levels and factors such as windows being open or closed.
- 6.31 There is a particular need for studies on the combined effects of exposure to traffic related air pollution and noise on the cardiovascular system and interaction effects between noise and other environmental stressors. Any future research in this area will need to clarify which component of air pollution is implicated in the various health effects studied.

- 6.32 It is recommended that access to a quiet side within a dwelling should be studied further in relation to health effects. In addition to this the modifying effects of shielding, room location, window opening, insulation, age, gender and other exposures (e.g. air pollution) and possible vulnerable groups warrant further study.
- 6.33 New, less studied, cardiovascular disease endpoints could include the measurement of stroke, long term cortisol measurement from hair, measurements of thickness in the carotid artery, non-dipping of blood pressure and heart rate variability.
- 6.34 The future needs in annoyance research include updating dose-response relationships, particularly noting the increase in annoyance over recent years. Indeed, the interaction between noise annoyance and other environmental annoyances remains a gap. There is a need to design a combined model of all the interrelations between noise exposure and annoyance and non-acoustic factors in order to further explore the pathways that exist between noise, annoyance and other health endpoints.
- 6.35 There is a requirement to distinguish between spontaneous and induced awakenings during noise-induced sleep disturbance. Sleep disturbance may also have effects on memory consolidation and performance at work the following day. It is also important that nocturnal noise exposure may contribute to the onset of other diseases.
- 6.36 The definition of vulnerable groups to sleep disturbance was discussed. Vulnerable groups may be defined by lower thresholds for disturbance and/or stronger reactions to noise. Groups that are thought to be vulnerable include children, those with existing ill health, insomniacs and older persons.
- 6.37 It is important to clarify the association and mechanisms that exist between sleep disturbance and disease; to quantify and compare the noise dose that would contribute to disturbed sleep with other factors e.g. light. Vulnerability needs to be examined in terms of noise sensitivity, light sleepers, old age; and there is a need to establish valid dose-response curves for cardiovascular response during sleep and noise.
- 6.38 Further research is also required on noise exposure during the day that might affect sleep. Future studies should also control for 'normal' arousals and heart rate variability during Rapid Eye Movement (REM) sleep stages.
- 6.39 Research priorities in mental health include longitudinal studies using standardised clinical interviews to measure psychiatric disorder. These studies should involve multiple, environmental and social stressors particularly focussing on high levels of noise exposure and accompanying mental health outcomes with hormonal and physiological measures.

- 6.40 There is a need to understand the burden of disease and disability-adjusted life years in relation to noise exposure and cognitive impairment. To this end, longitudinal studies are needed for understanding the causal pathways between noise exposure and cognition. The long-term consequences of aircraft noise exposure, during early school life, on later cognitive development and educational outcomes have not yet been studied and remain important for policy making decisions. It is recommended that greater understanding is needed of the mechanisms of working memory and episodic long-term memory in children in relation to noise effects.

Chapter 7

Summary and conclusions

- 7.1 This paper has examined research evidence published since 2009 relating to transportation noise, in particular aircraft noise and the resulting impacts on various health endpoints. These included cardiovascular disease, night-time effects on sleep disturbance, children's cognition, psychological effects, performance and annoyance. The paper also reports on emerging research areas and health impacts not covered above such as associations with metabolic outcomes (obesity) and foetal development.
- 7.2 Research showing an association with aircraft and road noise and cardiovascular disease measures continues to mature. There is emerging evidence to suggest that cardiovascular effects are more strongly linked with night time noise exposure as opposed to day or total (24hr) noise exposure.
- 7.3 With regard to night noise and sleep disturbance, there is growing recognition that average indicators such as L_{night} are insufficient to fully predict sleep disturbance and sleep quality and that use of number of noise events (LA_{max}) will serve to help understanding of noise-induced sleep disturbance.
- 7.4 With regard to aircraft noise and children's learning, further explorations of past studies have taken account of confounding factors not previously considered such as air pollution and concluded that these did alter the associations previously found. A number of studies, whilst reporting associations in primary school children, discover that the effects do not persist in secondary school aged children.
- 7.5 There is a greater understanding of the importance of accounting for confounding factors, in particular air pollution, which is often highly correlated with aircraft and road traffic noise exposure.
- 7.6 With regard to future research there is increased interest in incorporating the relative contribution of different transport noise sources and to also include the cumulative noise exposure in studies. The European Network of Noise and Health (ENNAH) has successfully drawn on European-wide expertise and research and has identified a number of gaps for future research considerations and will likely play a major role in this subject area going forward.

Appendix A

References

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