

# Aircraft noise, sleep disturbance and health effects

**CAP 1164**



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## Executive summary

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This report is an update to ERCD Report 1208, and serves to provide an overview of recent developments since the publication of 1208 in January 2013 in the research field of aircraft noise, sleep disturbance and health effects. This report was commissioned by the Department for Transport to provide an up-to-date account of current knowledge in this area.

**CHAPTER 1****Background**

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- 1.1 This report was commissioned by the Department for Transport and provides an update to the literature review (ERCD 1208) published in early 2013. That report summarised the main health effects associated with night-time aircraft noise, and suggested a potential method for monetising the impact of night flights in the UK. In conjunction with ERCD 1208, a second report was also published (ERCD 1209), that proposed a methodology for estimating the cost of sleep disturbance from aircraft noise. This update does not affect the recommendations offered in that report.
- 1.2 This paper was commissioned to take account of, and review several recent reports that have been published in the environmental noise and health effects area since ERCD Report 1208 was published. Two of these publications use data around Heathrow airport to investigate cardiovascular impacts of aircraft noise. European work has included the final report from the European Network of Noise and Health (ENNAH), which is the largest network of noise and health researchers to date and includes recommended directions for future research, and identified current knowledge gaps. In addition, Babisch from the Federal Environment Agency in Germany has published a meta-analysis of noise and exposure response curves for transportation noise and cardiovascular diseases. Further afield, a Harvard study attempts to examine the cardiovascular impacts around 89 airports within the USA and the Partnership for AiR Transportation Noise and Emissions Reduction (PARTNER) literature review on the potential health effects of aircraft noise is also referred to within this update as this work was previously omitted from ERCD 1208.
- 1.3 It should be noted that although these publications are not night-time specific, they are potentially relevant to night time effects of aircraft noise and have therefore been included as a more general update to the original literature review.

## CHAPTER 2

# Recent UK studies

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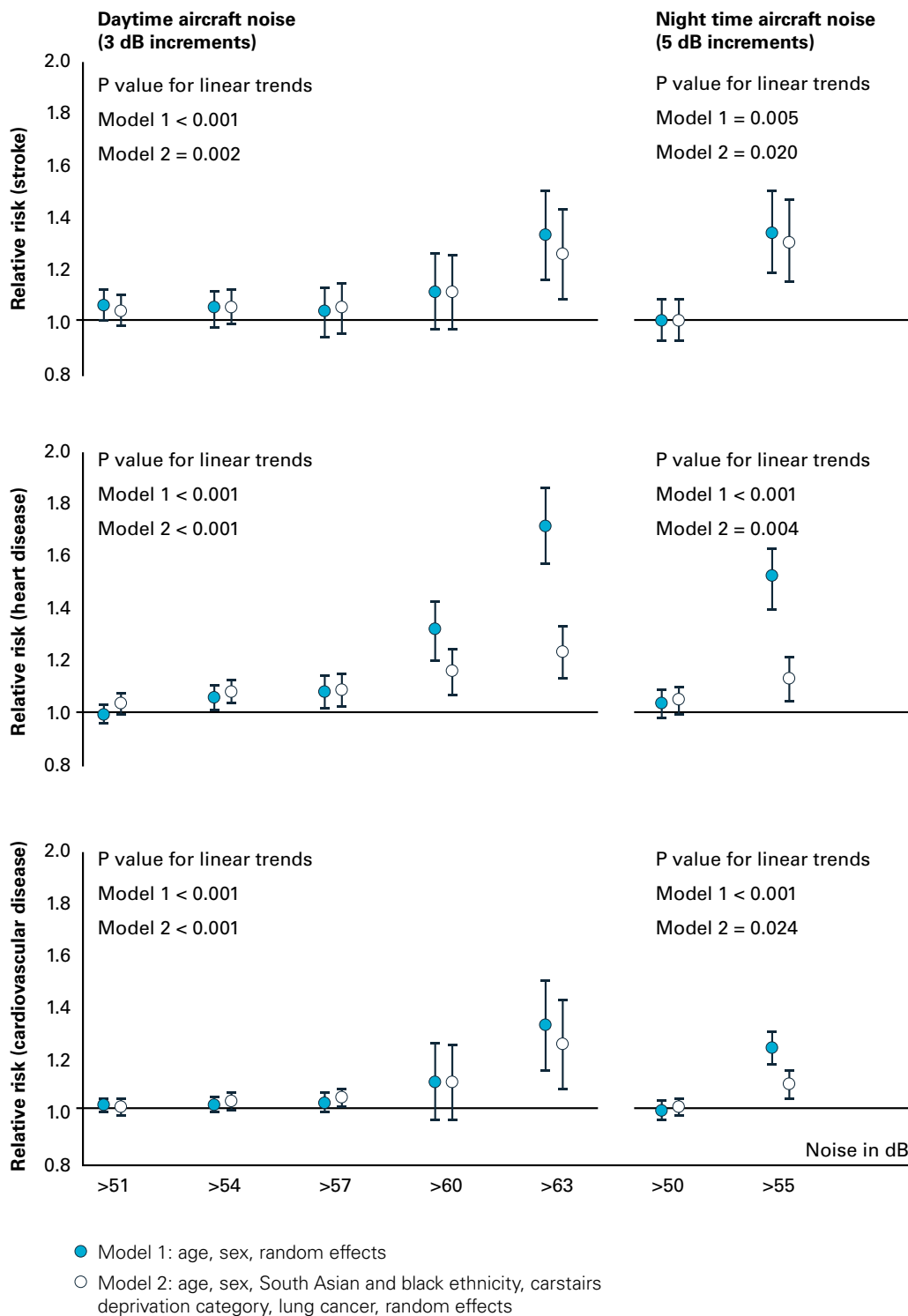
- 2.1 The findings from two studies focused around Heathrow airport were published in late 2013, and attracted considerable media attention due to the possible aircraft-noise induced health impacts on UK residents living in this vicinity that were identified.

## Hansell et al

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- 2.2 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.
- 2.3 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 50 dBA daytime ( $LA_{eq, 16_h}$ ). For the twelve London boroughs data on air pollution in the form of particulate matter ( $PM_{10}$ ) 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.
- 2.4 Daytime aircraft noise and road noise was grouped into six categories from  $\geq 51$  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  $\leq 50$ ,  $>50$ , 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.

2.5 The main findings on the hospital admissions with regard to stroke, coronary heart disease and cardiovascular disease are shown in Figure 1. With increased aircraft noise the risk of hospital admission also increased, with adjustment for ethnicity, deprivation and smoking included.



**Figure 1:** 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).

- 2.6 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.
- 2.7 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<sub>eq, 16h</sub>. 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<sub>eq, 16h</sub> to those exposed to 51 dB LA<sub>eq, 16h</sub> 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.
- 2.8 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 PM<sub>10</sub> 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.
- 2.9 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 PM<sub>10</sub>, they did not include exposure to Nitrogen Dioxides (NO<sub>2</sub>), possibly because NO<sub>2</sub> is primarily linked with respiratory disease rather than cardiovascular disease. However, considering that NO<sub>2</sub> 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.

- 2.10 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.
- 2.11 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.
- 2.12 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.
- 2.13 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.
- 2.14 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.

- 2.15 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.

## Floud et al

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- 2.16 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.
- 2.17 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 40 dBA, so the cut-off levels are likely to be below ambient noise exposure levels in much of the study areas.
- 2.18 In those study, as a possible confounder, nitrogen dioxide ( $NO_2$ ) was estimated at participants' addresses using dispersion modelling in the UK, Netherlands and Sweden.

- 2.19 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. Interestingly the daytime aircraft exposure had no significant association with heart disease and stroke before and after controlling for confounders.
- 2.20 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 NO<sub>2</sub> levels, with moderate correlations found between road noise exposure and NO<sub>2</sub>. 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 NO<sub>2</sub>. When NO<sub>2</sub> levels were factored into the analysis for subsamples of 24-hour road noise exposure, the significant association was lost, which suggested that NO<sub>2</sub> is a confounding variable in this relationship.
- 2.21 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.
- 2.22 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.

- 2.23 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 NO<sub>2</sub>. This is not unexpected, since road traffic is the predominant contributor to NO<sub>2</sub> 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.
- 2.24 Although this study attempted to analyse air pollution as a confounding variable, the choice to use NO<sub>2</sub> alone does not fully represent the particulate matter that is associated with transport emissions. Finally, although education level was controlled for in this study, it is possible that the results may be confounded by measures of socioeconomic status such as income or area-level deprivation.
- 2.25 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.

**CHAPTER 3****European research**

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- 3.1 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.
- 3.2 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.
- 3.3 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.
- 3.4 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.
- 3.5 ENNAH also concluded that increased interaction with policy makers regarding requirements for noise and health research objectives and strategies within the EU is an important future recommendation.
- 3.6 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.

## **Management, structure and work packages**

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3.7 The structure was to divide the overall aims and objectives into work packages, with an appointed leader for each package, although ultimately the whole project was co-ordinated by Queen Mary University of London.

### **Work Package 1 – Management of the ENNAH network.**

The main aim of this work package was the management and coordination of the network to ensure that objectives were realised on schedule and within the budgetary limits and to ensure a quick and smooth communication and decision making process existed within the network and with the Commission.

### **Work Package 2 – Review of evidence of environmental noise effects on health.**

The aim of work package 2 was to critically assess previous reviews and identify new studies to provide a state of the art summary of knowledge and to make recommendations for further research on environmental noise and its health effects.

### **Work Package 3 – Noise exposure assessment for health studies.**

There were two aims in this work package. The first was to investigate the current practice of noise exposure assessment and of strategic noise mapping in Europe and its potential use for epidemiological health. The second was to identify novel methods and advanced measurement and modelling techniques for exposure assessment in future studies.

### **Work Package 4 – Confounding and effect modifying factors in noise related health research.**

The aim of this work package was to investigate the potentially important confounders and effect modifiers in noise related health research. These included exposure modifying factors, such as room orientation to the noise source and the effect of modifying factors such as noise sensitivity.

### **Work Package 5 – Measurements of health outcomes in epidemiological studies on noise and European Health Impact Assessment.**

The aims here were firstly to discuss the improvements in the measurement of health outcomes in epidemiological studies on noise and to arrive at a consensus on standardised methodologies to be used in future studies. The second aim

was to compare the approaches and methods currently used in Health Impact Assessment (HIA) to promote common criteria for conducting a Europe-wide evaluation.

### **Work Package 6 – New strategies for noise and health research in Europe.**

The focus here was on the development of new strategies and priorities for noise and health as the primary outcome of the ENNAH Network.

### **Work Package 7 – Information strategy plan and dissemination of findings.**

This work package concerned the communication of the ENNAH findings to a wide range of audiences such as policy makers, NGOs, scientific community, the general public and industry.

- 3.8 In relation to night time noise exposure and potential health effects, the most relevant work packages were 3 and 6, and are described here.

### **Results of Work Package 3 – Noise exposure assessment**

- 3.9 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.
- 3.10 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 in 2007 and 2008, 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.
- 3.11 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.

- 3.12 One of the suggestions from this work package is the use of 35 dB during the night and 45 dB 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 with aircraft noise as the background noise can often exceed these levels, making it very challenging to separate the aircraft noise from ambient levels. Another suggestion from this work package is that individual levels rather than 5 dB contour bands should be available and vice versa. In health studies cut-off values should be introduced at the lower end.
- 3.13 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.
- 3.14 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.
- 3.15 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. A priority for future directions within this work package included the need to disentangle noise and air pollution effects. This will enable clearer understanding of the mechanistic pathways involved in their relationship with health outcomes. Increased research into the assessment of noise and air pollution exposure is important, as well as investigation into the relative contribution of each to their exposure-response relationships. Urban areas affect the transmission of noise and dispersion of air pollution, leading to lower correlations between both exposures. The researchers within this group cautioned that poor exposure characterisation may affect the assessment of exposure and distort subsequent dose-response relationships. It should be noted, however, that it is important to take into consideration the risk of double counting when attempting to separate out these two effects on human health.

## **Results of Work Package 6 – New strategies for noise and health research in Europe**

- 3.16 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.



- 3.17 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.
- 3.18 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.
- 3.19 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.
- 3.20 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 (air pollution for example) and possible vulnerable groups warrant further study.
- 3.21 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.
- 3.22 The future needs in annoyance research include updating dose-response relationships, particularly noting the evidence regarding the increase in annoyance at a given exposure over recent years reported by studies such as ANASE. Clearly caution should be taken when relying on or interpreting the findings from this particular study, which was not deemed to show robust evidence for a change in annoyance levels due to aircraft noise in the UK. Other European studies from Switzerland, Germany and the Netherlands have indicated that there has been an increase in annoyance since the 1990s, although this is compared to mainly studies from the US and Australia pre-1990s. It is not known what the cause of the change during this time may

have been, although this did coincide with the introduction of the ISO-standard questionnaire. 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.

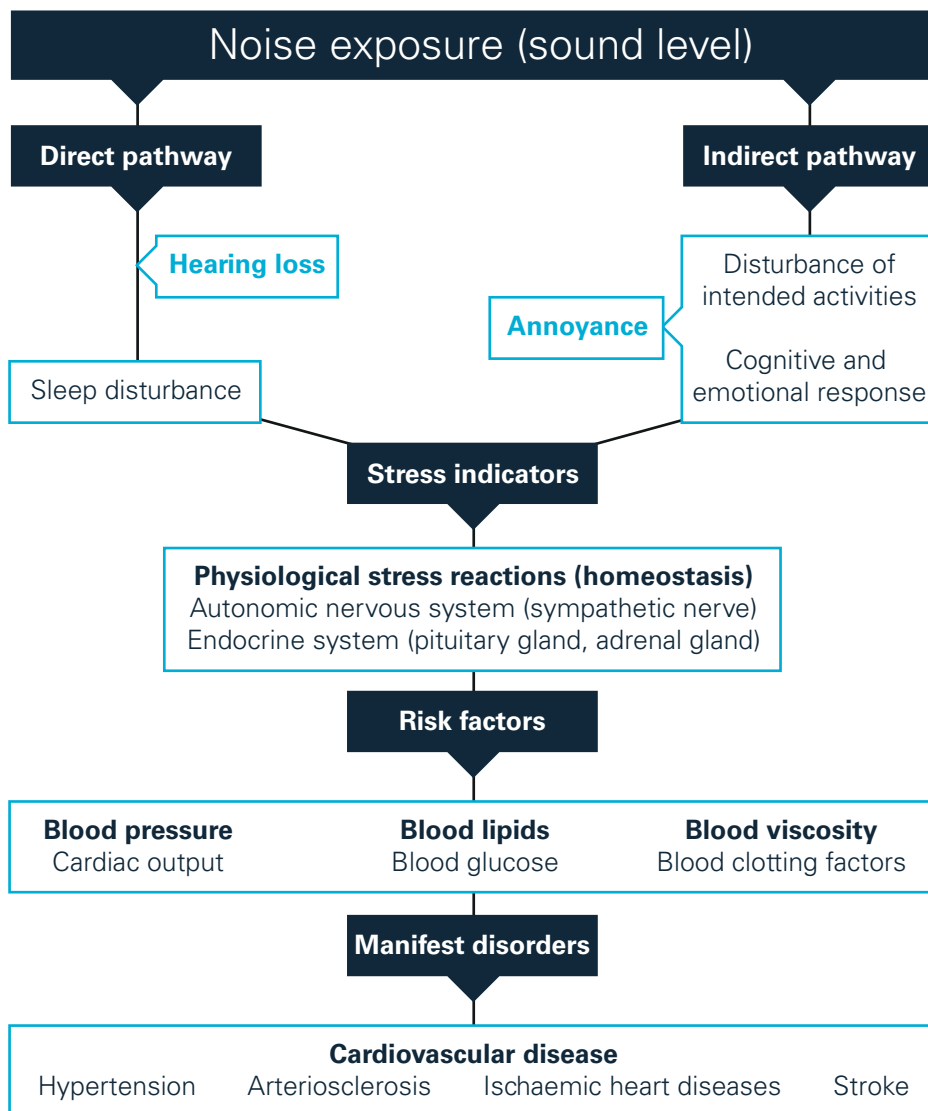
- 3.23 There is a requirement to distinguish between spontaneous and induced awakenings during noise-induced sleep disturbance. Sleep disturbance may also have effects on memory consolidation and performance at work the following day. It is also important that nocturnal noise exposure may contribute to the onset of other diseases, which needs further investigation.
- 3.24 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.
- 3.25 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.
- 3.26 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.
- 3.27 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.
- 3.28 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.

## Babisch meta-analysis

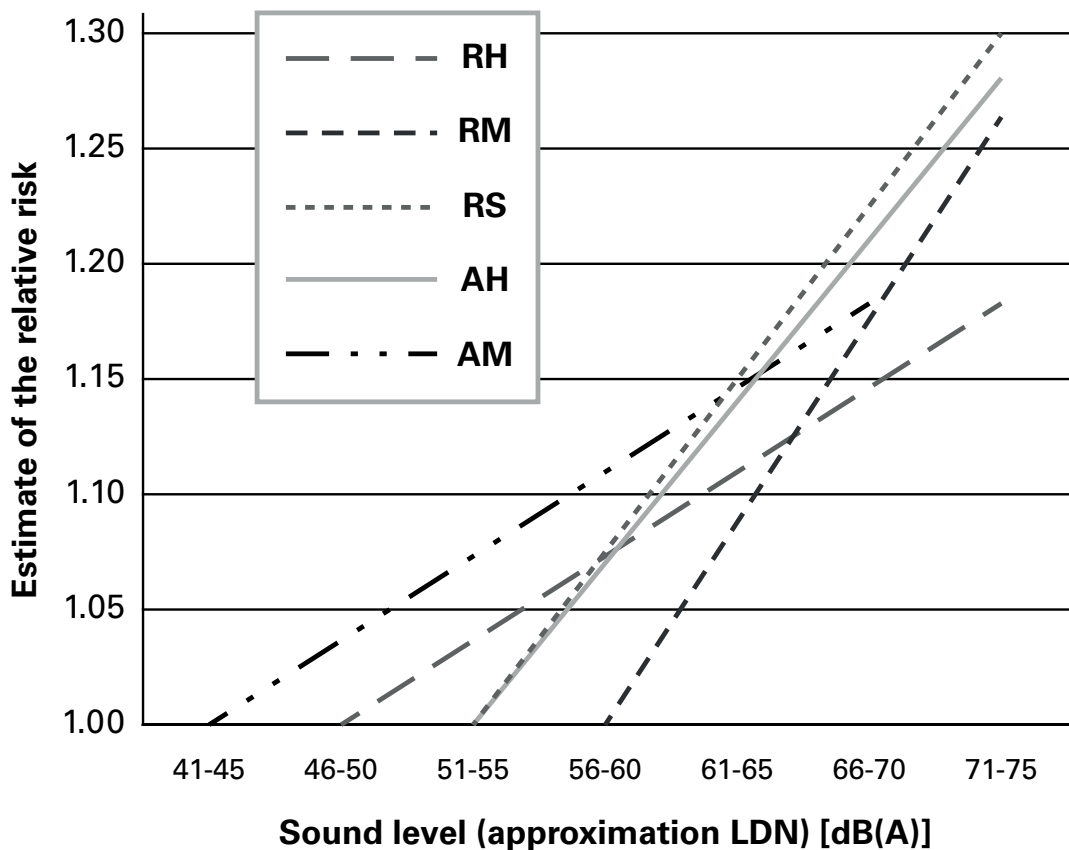
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- 3.29 In 2013 Babisch published a meta-analysis of noise and exposure-response curves between transportation noise and cardiovascular diseases. When considering epidemiological research approaches, Babisch stresses the importance of having a biological model for of 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.
- 3.30 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 2.
- 3.31 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.

3.32 The exposure-response relationships are shown in Figure 3, 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 Ldn of 40 dBA to 60 dBA.



**Figure 2:** Noise reaction chart, updated version. Taken from Babisch, 2013.



**Figure 3:** Exposure-response curves of the association between transportation noise and cardiovascular diseases. RH = road traffic noise – hypertension, RM = road traffic noise – myocardial infarction, RS = road traffic noise – stroke, AH = aircraft noise – hypertension, AM = aircraft noise – myocardial infarction.

3.33 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. 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.

## Internoise 2013

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- 3.34 Various other papers that are relevant to aircraft noise exposure and health effects were published or presented at Internoise 2013 since the last literature review. Matsui from Hokkaido University in Japan reported findings on psychosomatic disorder due to aircraft noise. The study re-analysed previous data obtained from a study in Okinawa around Kadena and Futenma military airfields. This study had shown a dose-response relationship between the prevalence of psychosomatic disorder (PSD) and Ldn of aircraft noise based on responses from the Total Health Index (THI) questionnaire. PSD was diagnosed from a Discriminant Function (DF) score calculated from the answers to the THI questionnaire. The purpose of this study was to re-analyse the data to examine the causal pathway of this relationship and the answers on disturbances to daily life due to aircraft noise (which was obtained from another questionnaire given to the same subjects). The DF score of PSD was analysed with sleep disturbance and speech interference, in relation to day-time and night-time noise exposure. The results indicated that the PSD score around Kadena airfield was significantly associated with sleep disturbance, and the annoyance score was more highly associated with speech interference than sleep disturbance. The conclusion given by the author was that in this location, PSD due to aircraft noise is actually a result of sleep disturbance. These results corroborate those found from a new Narita study, and analysis on hypertension observed around Kadena airfield, which also found that night-time noise was correlated with prevalence of hypertension.
- 3.35 It should be emphasised that military aircraft is typically somewhat different to that associated with civil airports, being composed of louder, but less-frequent events. Historical annoyance surveys around military airfields have tended to show elevated responses for a given noise exposure level.
- 3.36 Evrard from the University of Lyon, France, gave a paper at Internoise 2013 on sleep disturbance effects from aircraft noise near Paris-Charles de Gaulle airport. The findings presented were from a pilot study undertaken as part of the DEBATS research program, running from 2011-2018 involving adult residents and health effects around French airports. The program includes a sleep study with the aim of measuring acute effects of aircraft noise on sleep quality using accurate noise exposure measurements. This study was the pilot study designed in 2011 to test and validate the intended protocol. Twelve participants wore actiwatches for seven nights and completed a sleep diary in order for their sleep quality to be ascertained. A sound monitor was located inside the participants' bedrooms to record noise levels during the study, and a second one was placed outside at the bedroom façade, to enable researchers to identify aircraft noise and to evaluate the impact of this noise inside the bedroom. This study allowed energetic indicators,  $L_{\text{night}}$  for example, as well as noise event indicators to be measured, which enabled the link between noise levels and numbers

and sleep quality to be investigated. The results indicated that the strongest associations were found between sleep quality and noise events indicators that were estimated inside the bedroom. This was a pilot study with only twelve participants, and it is expected that in the full study heart rate monitors will be worn alongside actiwatches to increase the accuracy of sleep arousal measurement. It is also planned that over 100 participants will be included in the main study. Evrard suggested that the energetic noise indicators used by the European regulations and recommendations may not be sufficient when sleep quality is concerned. More information will be available following the next phase of the research program.

- 3.37 In addition to the previous paper she gave, Evrard presented the cardiovascular results of the DEBATS research programme pilot study. The aim is to study 1,200 residents around three French airports over four years. Questionnaires on socioeconomic status, lifestyle, medical history, medication and annoyance were administered. Objective physiological measurements of blood pressure and heart rate were assessed three times and a mean value taken. In this pilot study there was no significant exposure-relationship found between aircraft noise exposure and hypertension. It was stressed, however, that this may be due to selection bias issues and sample size. For the main study it was explained that researchers plan to separate day and night aircraft noise exposures, and also include road traffic and air pollution levels.
- 3.38 Zur Nieden from the Institute for Hygiene and Environmental Medicine, Germany, gave a presentation on the NORAH (Noise-Related Annoyance, Cognition and Health) study. This paper focused on blood pressure monitoring using telemedicine to investigate the association between blood pressure and aircraft, road and rail traffic noise.
- 3.39 The study examines health effects of transport noise around Frankfurt airport and contains three work packages:
- WP1: Annoyance and HQoL (quality of life)
  - WP2: Health effects
  - WP3: Children's learning
- 3.40 The study arose from a requirement to conduct a longitudinal study on aircraft noise and subsequent effects, and was started in 2011 with the first results expected in mid-2015. The objectives are to identify potential risk factors for diseases, the relationship between exposure to aircraft noise and health outcomes, and the effect of aircraft noise on children's learning and quality of life measures. The study incorporates a comparison of responses to transportation noise (aircraft, road and rail) and expanding (Frankfurt and Berlin) versus steady state airports (Cologne-Bonn and Stuttgart).

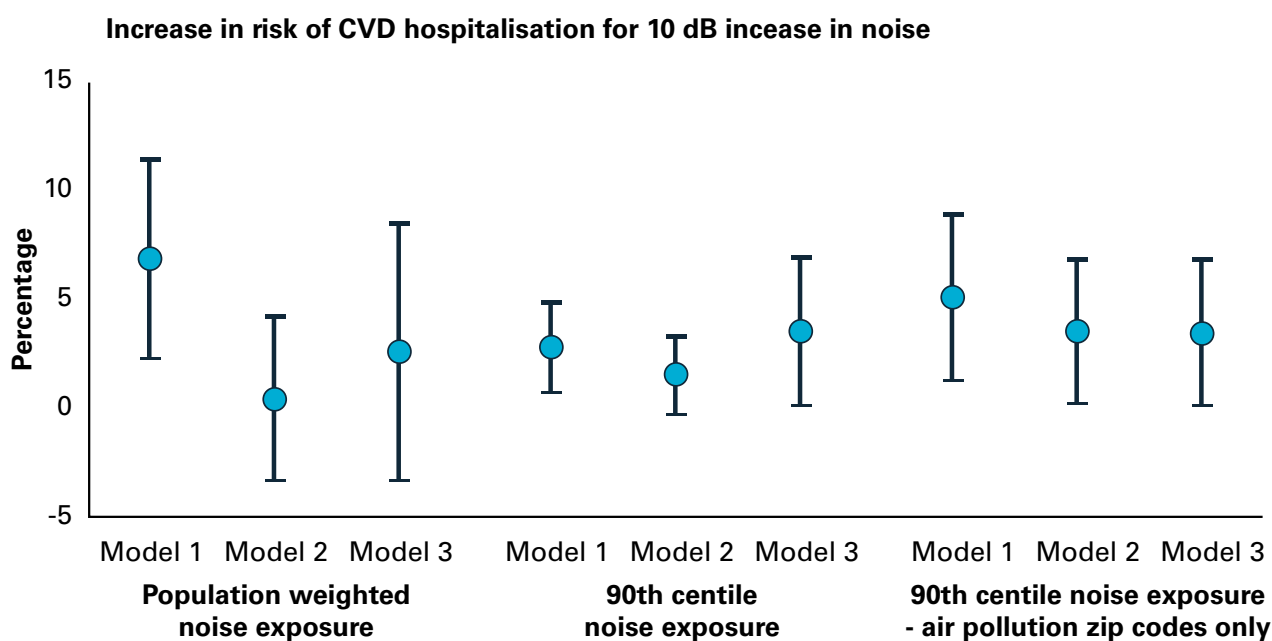
- 3.41 The study is expected to provide several new insights, for example the change in aircraft noise exposure since previous studies, the comparison between different transportation noise sources, the relationship between noise level, annoyance and stress response and resulting impact on health. Exposure-relationship curves for awakenings have been produced by the DLR study team in 2001/2002 for Cologne-Bonn and this study aims to do the same for Frankfurt airport. This study will also examine if there is a change in sleep quality after a night flight ban from 2300-0500 at Frankfurt.
- 3.42 The health measures that are examined in this study include blood pressure monitoring to investigate the effect of changes of aircraft movements and noise, resulting in an exposure-relationship for cardiovascular disease and aircraft noise. The analysis of health insurance data is incorporated combined with a case-control study including the assessment of individual risk factors of cardiovascular disease. Analysis of individual noise history, the impact of aircraft noise on children's learning, phonological processing and nocturnal aircraft noise on cognitive performance is also included in the design of this study. This presentation concerned the longitudinally designed blood pressure study, which aimed to analyse whether blood pressure as well as the risk of cardiovascular diseases in total is associated with aircraft noise exposure, road traffic and railway noise and whether the changes in the flight operations due to airport expansion correspond with changes in the average blood pressure over time. The study includes residents living within the 40 dB contour, and individual exposure includes  $L_{eq}$ ,  $L_{max}$  and  $N_x$  (number of events above a specified level). 2000 participants were trained to assess their blood pressure in the morning and evening on 21 consecutive days, and complete questionnaire on cardiovascular risk factors. The same participants were asked to repeat the same measurements in the follow-up study one year later. Bluetooth was used to send the blood pressure measurements to a mobile phone, which is then used to forward the real-time measurements to a secure database. The observation period for this study has just finished, so the results will be published in due course. The NORAH study is particularly interesting as it spans cardiovascular effects, sleep disturbance and children's cognition.



**CHAPTER 4****USA research**

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- 4.1 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.
- 4.2 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.
- 4.3 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.
- 4.4 To address confounding variables such as socioeconomic status the researchers concluded that the percentage of Hispanic and the median household income would be the two key variables included in the analysis. Air pollution in the form of particulate matter  $PM_{2.5}$  and ozone concentrations were included, as well as postcode level road density to control for road noise and road-related air pollution.
- 4.5 Of the 2,218 postcodes studied, 779 included 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.



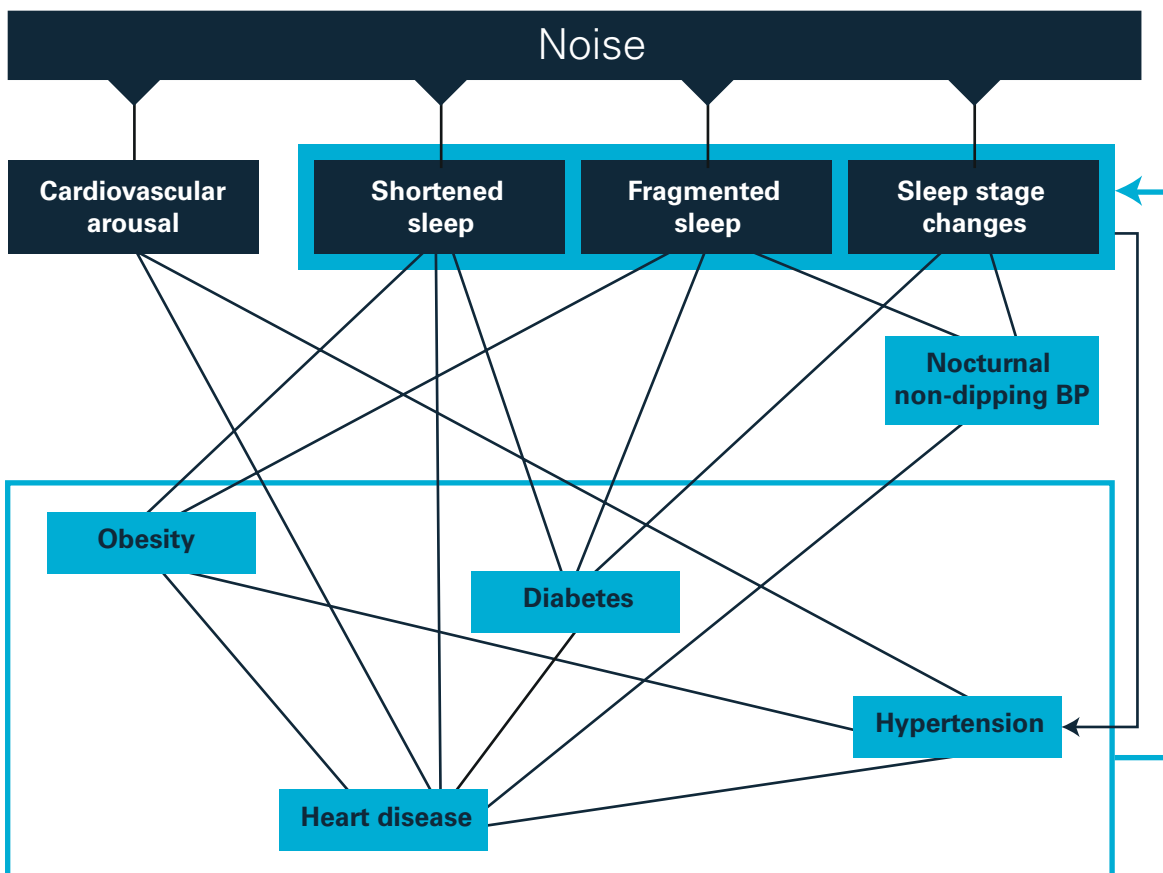
**Figure 4:** Overall estimates (averaged across 89 airports) of percentage increase in hospital admission rate for cardiovascular disease (CVD) associated with 10 dB (day-night sound level) increase in both exposure variables (population weighted noise exposure and 90th centile noise exposure) for each 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).

4.6 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.

- 4.7 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.
- 4.8 A potential 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.
- 4.9 The INM model has limitations also, due to the use of average annual input which may mean that values could lack accuracy due to local acoustical variables not being accounted for.
- 4.10 This study did not differentiate between day time and night time noise exposure, so it was not possible to examine the contribution effects of potential sleep disturbance, 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.

## PARTNER work

- 4.11 In 2010 the Partnership for AiR Transportation Noise and Emissions Reduction (PARTNER) in the US published a literature review on the potential health effects from aircraft noise. The report was authored by Swift of Purdue University, and was funded by the U.S. Federal Aviation Administration Office of Environment and Energy. This report was centred on two well-known European research projects, namely the HYENA study, and the 2006 Babisch meta-analysis of transportation noise and cardiovascular risk.
- 4.12 This literature review focuses on the ways in which sleep could possibly be disturbed by aircraft noise, and then potential ways in which this sleep disturbance could be linked to health outcomes. One of these is the possibility of sleep disruption and deprivation leading to changes in the sympathetic nervous system and potential changes in the appetite hormones leptin and ghrelin, resulting in health outcomes such as obesity and diabetes which then may lead to hypertension and cardiovascular disease. This theory is summarised in Figure 5.



**Figure 5:** Proposed potential pathways for the health effects of noise through sleep disturbance. Reproduced without permission from the PARTNER report, 2010. Non-dipping blood pressure refers to the absence of a nocturnal decrease in blood pressure that usually occurs during sleep.

- 4.13 The report acknowledges that long and short term physiological changes in response to noise exposure while awake and short term physiological changes while sleeping have been previously observed, but there are still several issues that need to be addressed and researched in more detail. These include the intensity of effects, relative contributions of noise exposure in multiple settings, multiple or differing noise sources (aircraft versus rail or road traffic noise for example) and the relative importance of exposure while awake versus exposure during sleep. The question of vulnerable groups was also raised, and what may constitute groups that are particularly susceptible to noise. Air pollution has been looked upon as often co-varying with noise and future research could potentially benefit from means to systematically take both noise and air pollution variables into account. Similar measurements of exposure could be accomplished if people were willing to allow tracking through GPS, or long-term noise dosimetry. Further possible pathways that may be valuable to research include the action of the hypothalamic-pituitary-adrenal (HPA) axis, a postulated role of cholesterol, as well as the role of stress. Possible immune system effects of sleep disruption may also justify further examination.
- 4.14 The report covers the study designs and methodologies used in noise effects research, an introduction to the physiological aspects of sleep and it describes in considerable detail the mechanisms by which sleep loss, deprivation or fragmentation may link to potential health outcomes. These include heart rate changes, alterations in sympathetic tone, connection of sympathetic tone with glucose mismanagement, obesity, the appetite regulating hormones leptin and ghrelin, immune effects of sleep loss, glucose regulation and diabetes, and cardiovascular non-dipping. The effects of noise that are included are memory, noise sensitivity, the relationship between annoyance and cardiovascular disease, performance decrements and task interference.
- 4.15 The methodologies used for the cost-benefit analysis of noise are discussed, with the consensus being that the use of Disability Adjusted Life Years (DALYs) is at present the most appropriate method for valuing the effects of noise. Because this measure is used widely to predict and evaluate the cost of other health outcomes, it is considered useful when making comparisons between the total impact on health of various exposure increases or interventions. For example, for communities near airports, the health effects cost of chemical and particulate exposure can be compared to the health effects cost of noise. Some drawbacks concerning this system include, for example, that it is seen as focusing disproportionate attention on measureable outcomes and poses difficulties for dealing with co-morbidities.

- 4.16 The role of stress is discussed and it was concluded that stress plays an important role in the genesis of cardiovascular disease and hypertension and is an important potential pathway in the relationship between noise and possible hypertension and cardiovascular outcomes. The relationship between noise and stress may be mediated by factors such as cardiovascular reactivity, cardiovascular recovery, rumination on stressors, anger toward a potential stressor and social support. The report recommends that these variables should be accounted for in future noise studies.
- 4.17 Questions remain as to the most relevant exposure types and environments and the best metrics with which to evaluate these risks. During the day and night people are exposed to many different sources of noise in a variety of contexts. Distinguishing between the exposure-contributions of multiple environments and sources could allow researchers in a prospective epidemiological study to determine which exposures and contexts are most relevant for health. The author suggests that this information could then be used by policy makers to regulate development in a way optimally suited to balance the risks and benefits of noise.
- 4.18 While some research findings concerning hypertension and heart disease seem to support a possible role of noise disturbance through sleep, other potential outcomes of sleep disrupted by aircraft such as obesity and diabetes have not been specifically investigated. The report suggests that future research could investigate the effects of a night or multiple nights of aircraft noise-disrupted sleep on the sympathetic nervous system, leptin and ghrelin signalling, and glucose management, as well as a further examination of the known short-term cardiovascular effects. Obesity is included as a confounder between hypertension and heart disease, due to its known relationship, but the report also points out that obesity may co-vary with lost or disrupted sleep. The author argues that by attempting to adjust it out of models may in fact reduce the strength of a real effect of sleep disruption on fat levels as well as the confounding effect of non-sleep-disruption-related obesity. The author suggests that a more sophisticated means of adjustment may be needed (if it is indeed possible) to remove effects of obesity not due to noise-related sleep disruption from data without removing those that are.

- 4.19 The report makes several recommendations for future research, such as the need to further examine the relationship between cardiovascular disease and hypertension with respect to night time noise exposure compared to day time noise exposure from aircraft. The author cites the Babisch (2006) meta-analysis finding of an odds ratio for myocardial infarction of 1.13 per 10 dB increase of  $L_{\text{day}}$ , the HYENA result of an odds ratio for hypertension of 1.14 per 10 dB increase of  $L_{\text{night}}$  and goes on to discuss a possible role of sleep disruption in the development of such outcomes, along with potential role of stress reactions. Although in general broader sleep studies hypertension and heart disease have been identified as potential outcomes of sleep disruption, the specific effect of aircraft noise on sleep is still not yet completely clear and the author cautions that they may well be small in magnitude for these particular health outcomes. The report suggests that obesity and diabetes which both correlate with reduced or disturbed sleep should be further examined in the context of aircraft noise.
- 4.20 It is suggested that modelling may be a way to predict potential health outcomes from aircraft noise, by using the results of previous noise related health studies and related dose-response relationships with sleep disturbance and noise prediction models to predict the probability of increases in such outcomes with an increase in noise. If the effects are deemed large enough to affect a population, it is proposed that a re-analysis of data that included potential confounding from body mass index to see whether an effect is observed, or in the addition of noise data to studies investigating obesity or diabetes. Consideration should be given when adjusting models of noise-induced health effects for obesity and diabetes as they themselves may be mediating variables in the relationship between noise and hypertension and heart disease.
- 4.21 The PARTNER report provides a useful exploration of the possible pathways by which health outcomes may arise from sleep disturbance in a general sense, and although much of this report is focussed on the potential pathways by which health effects may emerge due to noise, rather than actual known evidence, it does suggest some relevant directions for future work in terms of potential aircraft-noise specific health endpoints.

**CHAPTER 5****Conclusions**

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- 5.1 This report has provided an update of the literature on aircraft-induced noise and health effects that has been published since early 2013, and included the PARTER work from 2010. It is intended that this report is in addition to ERCD Report 1208, which examines the research on the potential health impacts of night time aircraft noise. With current ongoing studies into this area, such as the NORAH work in Germany which is due to finish in 2015 and other current research programmes such as DEBATS in France, this important field of research will continue to be observed and evaluated as appropriate and the findings from current and future work to add to present knowledge will be much welcomed.
- 5.2 It should be noted that this update does not affect the current recommendations in ERCD Report 1209 for proposing a methodology for estimating the cost of sleep disturbance from aircraft noise, which remains the same.
- 5.3 Later in 2014, it is intended to publish a broader review of noise and health research, including daytime effects.



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