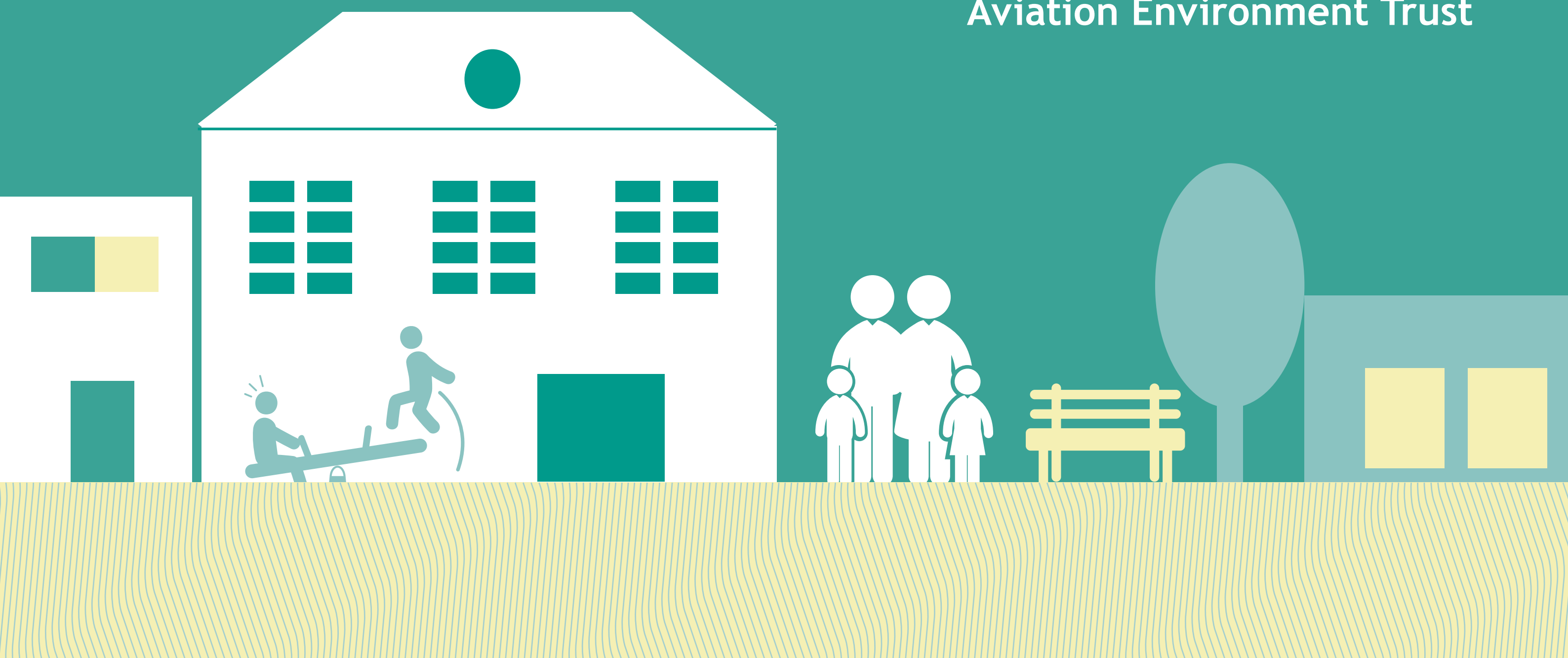
A new report by

Aviation Environment Federation

AIRCRAFT NOISE AND PUBLIC HEALTH

THE EVIDENCE IS LOUD AND CLEAR

Commissioned by HACAN and the
Aviation Environment Trust



'Aircraft noise and public health: the evidence is loud and clear' was commissioned by HACAN (Heathrow Association for the Control of Aircraft Noise) and the Aviation Environment Trust from the Aviation Environment Federation.

The report is available to download from the AEF and HACAN websites:
www.aef.org.uk
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The Aviation Environment Federation (AEF) is the only national NGO campaigning exclusively on the environmental impacts of aviation including noise, air pollution and climate change.

Supported by individuals and community groups affected by the UK's airports and airfields or concerned about aviation and climate change, we promote a sustainable future for aviation which fully recognises and takes account of all its environmental and social impacts. As well as supporting our members with local issues, we have regular input into international, EU and UK policy discussions. We have contributed evidence both in writing and in person to Parliamentary Committees and the Airports Commission. We participated in the European Commission's working groups that contributed directly to the publication of the Environmental Noise Directive, as well as EU and UK noise policy working groups, including the ANASE study steering group.

HACAN (Heathrow Association for the Control of Aircraft Noise) is the long-standing body which gives a voice to residents living under the Heathrow flight paths. Founded 50 years ago, it is now a regional body with members from Berkshire in the west to Greenwich and Blackheath in the east.

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The Aviation Environment Trust (AET) is a registered charity founded in 1978 to advance knowledge and understanding of aviation's environmental and amenity impacts, through research and education.

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ABSTRACT

Evidence that has accumulated over 20 years indicates that aircraft noise has pervasive impacts on public health around airports.

At least one million people's health in the UK could be affected by aircraft noise.

The health costs from aircraft noise across the UK have been conservatively estimated to be in the region of £540 million each year (See section 2.2.3).

However, aviation noise policy does not reflect the evidence on health.

We call on Government to update its overall aircraft noise policy to include specific long-term targets focussed on protecting the public from health impacts.

The Government should review its policies to take account of the latest health based evidence and ensure that policy decision making takes health fully into account and is in line with a long-term goal to reduce the health burden from aircraft noise.

Any new flightpath decisions must explicitly take health impacts into account and the Government should develop a new approach to understanding the 'change effect' of significant changes in noise exposure associated with new flightpaths.

The decision to build a new runway should be assessed on whether it helps to deliver health-based aircraft noise objectives. A new runway, as currently planned, is estimated to have noise related health costs of £3.7 billion (see section 2.2.4).

It is essential that the next night flights regime aims to reduce the severe health burden associated with sleep disturbance.

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EXECUTIVE SUMMARY

Aircraft noise is the primary environmental concern for communities around the UK's major airports, and residents are increasingly dissatisfied with levels of noise around where they live. The 2012 survey of public attitudes to noise by Defra, the UK Government's environment department, revealed that close to one third of those interviewed (31%) from a sample selected from across the UK were annoyed, disturbed or disrupted by aircraft noise levels where they lived, and 4% of those asked said their lives were severely disrupted by aircraft noise (Defra 2014b).

Aircraft noise can no longer be considered only as an inconvenience in people's lives. Major studies and reviews have concluded that aircraft noise is negatively affecting health and quality of life, even when other factors are taken into account. Exposure to aircraft noise can lead to short-term responses such as sleep disturbance, annoyance, and impairment of learning in children, and long-term exposure is associated with increased risk of high blood pressure, heart disease, heart attack, stroke and dementia. There is evidence to suggest that aircraft noise may also lead to long-term mental health issues.

Over one million people live in areas where aircraft noise over a 24 hour period is above levels recommended for health, while close to 600,000 people live in areas where night-time noise is above 48 dBA Lnight, far above WHO recommended levels. Aviation policy needs to be updated to take health impacts into account, and where the health impacts of aircraft noise are unacceptable, airspace or airport capacity changes should only be permitted if they contribute to reducing this impact.

> Key recommendation: Government should commit to developing specific long-term targets focussed on protecting the public from the health impacts associated with aircraft noise.

PART ONE: THE EVIDENCE

The report considers evidence for five areas, all of which are considered health effects by the WHO: sleep disturbance, annoyance, impacts on learning in children, cardiovascular diseases, and long term mental health. For each of the impacts considered, the strength of the relationship between environmental noise and a given health effect has been examined using the WHO's approach. The strength of evidence is marked as SUFFICIENT, LIMITED or INSUFFICIENT for each impact depending on the level of understanding of the magnitude of the effects; whether a causal association is consistent with existing biological and medical knowledge; and observation of an exposure-response relationship indicating the risk of a given health impact from a certain noise exposure level.

Immediate impacts

Sleep disturbance

Evidence strength: SUFFICIENT

Sleep disturbance from aircraft noise leads to next day fatigue, loss of productivity and can have major impacts on health and wellbeing. An aircraft noise event may lead to awakening or influence the time spent in different sleep stages which affects quality of sleep. WHO recommends that night noise should not exceed 40 dBA Lnight. The exact number of people exposed to night noise above WHO-recommended levels is unknown but in the UK around 600,000 people are exposed to night noise above 48 dBA Lnight.

Noise from a particular event, rather than average noise, is understood to be more relevant in terms of sleep disturbance. This provides an incentive for policy makers to use noise metrics relating to individual noise events when assessing the likely impact on sleep disturbance.

Sleep disturbance is, some studies suggest, particularly intrusive in the early morning when more time is spent in the restorative part of the sleep cycle, and noise during the evening and morning has relevance for children, the physically ill, and shift workers. Evidence indicates that the body's response to a noise event at night, even when the individual continues to sleep, may lead to increased risk of higher blood pressure and long-term heart disease.

Cognitive and emotional responses

Annoyance

Evidence strength: SUFFICIENT

Annoyance is the most widespread aircraft noise impact, and can lead to stress-related symptoms. People are more annoyed by aircraft noise than by noise from other forms of transport, and attitude surveys in the UK and across the EU have identified that annoyance from aircraft noise is increasing despite individual aircraft becoming quieter. Individuals react to noise differently and reactions depend on the context. For example, people have higher annoyance responses when there is a step change in noise exposure, such as the introduction of a new flightpath or sudden increase in aircraft movements. This has significance for airspace change policies. The stress response to an aircraft noise event is associated with increased blood pressure levels and so could in the long-term lead to higher risk of cardiovascular disease.

Impacts on learning in children

Evidence strength: SUFFICIENT

There is robust evidence from over 20 studies to demonstrate that aircraft noise exposure has impacts on children's reading comprehension or memory skills. The RANCH (Road traffic and Aircraft Noise and children's Cognition & Health) study found that a 5dB increase in noise exposure is associated with a 2-month delay in learning in UK primary school children. This finding was echoed in similar research as part of the NORAH study around Frankfurt Airport. An update to the RANCH study found indications of a long-term, cumulative impact from aircraft noise on memory and learning but the sample size was insufficient for the long-term relationship to be regarded significant. Around 460 schools around Heathrow are exposed to aircraft noise above 54 dBA Leq (16 hours), higher than the onset threshold of the effect on children's memory and learning, but the airport has so far paid for insulation of only 42 community buildings in total.

Long-term responses

Cardiovascular diseases

Evidence strength: SUFFICIENT for hypertension and several major studies have found significant associations for increased risk of heart disease, heart attack, stroke and dementia, but in some cases the direct evidence is LIMITED.

Several large-scale UK studies over the past 10 years have found increased risk of high blood pressure, heart disease, heart attack, stroke and dementia associated with higher exposure to aircraft noise. Babisch has argued: "the question is no longer whether noise causes cardiovascular diseases; it is rather to what extent" (Babisch 2014). Hansell et al. (2013) found people around Heathrow exposed to high levels of aircraft noise (above 63 Leq 16 hour average daytime noise) had a 24% higher chance of stroke, 21% higher chance of heart disease, and 14% higher chance of cardiovascular diseases compared to people exposed to less than 51 dBA. Another study by Jarup et al. (2008) found that people had 14% higher blood pressure per 10 dB increase in aircraft noise at night.

A well-developed 'dose-response curve' (where the likely change in risk can be assessed for certain noise levels) exists for transport noise and increased risk of heart attack, and a dose-response relationship exists for aircraft noise and hypertension based on a large-scale review, from which it is possible to estimate the increased risk of dementia and stroke. Further work is needed to develop the evidence base and improve understanding of what the health response is from a specific noise dose.

While the increase in risk appears to be moderate, it has importance for public health when large populations are exposed. It also appears that night-time noise could be more important for cardiovascular health than day noise.

Long-term mental health

Evidence strength: INSUFFICIENT

There has been insufficient research into whether aircraft noise has long-term mental health impacts, with a recent review concluding that current evidence indicates that aircraft noise is associated with decreased quality of life but is unlikely to be causing psychological ill health through annoyance (Clark 2015). However, the recent NORAH study around Frankfurt Airport found that high aircraft noise levels were significantly associated with high levels of depression even after accounting for other factors. The study found that for every 10 dBA increase in noise the risk of depression increased by 8.9%. This relationship was found to be even stronger for people who were psychologically sensitive.

Supplementary Recommendation 1: The Government should draw on all available evidence including the upcoming WHO guidelines, the upcoming DfT noise attitudes survey and any other recent research (including the research summarised in this report), in setting its long-term objectives for aircraft noise.

PART TWO: THE POLICY RESPONSE

The World Health Organisation (WHO) has reviewed the latest evidence on the health impact of transport and industrial noise and, in its guidelines on community and night-time noise, recommends long-term noise limits to protect public health, along with an interim target that would deliver more limited health benefits. WHO has also set out a methodology for assessing the impact of noise on a population using the best available evidence, providing policy makers with the tools to calculate the impact on public health of a particular noise source. New WHO guidelines are expected in 2016 which will use the latest evidence to update the guideline values, and are expected to provide information on the latest understanding of how noise from specific sources leads to effects on health.

The WHO guidelines led directly to the Environmental Noise Directive, the EU's key noise policy, which requires member states to map out exposure to noise sources and to set action plans to tackle noise problems. The Directive does not set clear targets, health-based or otherwise, towards which noise should be reduced, despite the EU Environmental Action Plan aiming for noise pollution to significantly decline by 2020 towards WHO recommendations. The lack of an overall goal to reduce noise towards WHO recommendations is echoed in UK policy.

The UK Government's policy on aircraft noise is "to limit and where possible reduce the number of people significantly affected by aircraft noise", an approach which does not directly require consideration of the health impacts discussed in this report. The Government has also retained the 57 dBA Leq noise contour as marking the onset of significant community annoyance despite evidence indicating it is out-of-date.

The Government's policy on night noise from aircraft noise has been static for nine years, despite the Government acknowledging that "long term exposure to noise at night can result in adverse health effects" (DfT 2013a), and despite a growing disconnect between the policy and the evidence. Close to 600,000 people are affected by aircraft noise at night above levels damaging to health and several major studies have found long-term negative health effects associated specifically with night noise. The environmental objectives for the current night noise regime at Heathrow, Gatwick and Stansted airports do not reflect evidence on the need for alternative noise metrics.

The Government's flightpath policy is being updated but it currently doesn't directly consider potential noise-related health impacts of flightpath changes, or refer to the evidence suggesting that a step change in aircraft noise exposure is likely to generate significant annoyance and disruption to quality of life.

Supplementary Recommendation 2: the Government should review all existing policies to ensure they take full account of the health impacts from aircraft noise and that any changes are permitted only if they help to deliver the long-term noise goals.

Informing decision making

The assessment criteria for noise impacts from a new runway in the South East used in the recent work by the Airports Commission were based on the Government's current noise policy, which does not consider whether or not the health burden from aircraft noise should be reduced. The Airports Commission also made recommendations on prioritising insulation in schools based on evidence of the impacts of aircraft noise on children. However, while over 460 schools are exposed to levels of aircraft noise that could affect memory and learning, so far Heathrow has only insulated 42 community buildings in total. Without changes to the Government's insulation policy, the proposed level of insulation is unlikely to protect children's health and educational attainment.

It is possible to assess the likely impact on the health of a population from exposure to aircraft noise, which can then be used to inform decision-making. The Government's new noise monetisation methodology focuses on health impacts. AEF used this methodology to assess health impacts from exposure to aircraft noise across the UK, **finding a total annual cost of £540 million per year.** Annoyance and sleep disturbance had the most significant impacts on health (contributing to the highest costs). While cardiovascular costs are lower, they are more closely related to increased risk of premature death.

The Airports Commission calculated a monetary value for the health impacts of aircraft noise to inform its cost-benefit analysis, providing a total health cost from aircraft noise associated with **an additional runway of up to £3.7 billion**. AEF's view is that while monetisation has a valuable role in the policy process the Government should also assess the health impact of any policy proposal, taking account of the differential impacts for different social groups, including children and the elderly, through a health impact assessment.

Monetisation is also no substitute for the setting of appropriate targets to protect the public from the health impacts of noise. The Government should set appropriate targets for noise levels and any upcoming policy decisions should be assessed in terms of whether they make progress towards these targets.

Upcoming policy decisions include:

1) Airport expansion in the South East including the development of an aviation National Policy Statement

The Government needs to clearly demonstrate that it has a plan to ensure that a new runway would be compatible with health-based noise targets before proceeding. In addition, a full health impact assessment should be carried out to make it clear what the health burden of a new runway would be, with a particular focus on vulnerable groups.

2) Review of night noise restrictions at Heathrow, Gatwick and Stansted

The Government's upcoming review of its night flight restrictions around Heathrow, Gatwick and Stansted should be informed by the major economic benefits of a full night flights ban outlined by the Airports Commission (up to £7.5 billion, just for Heathrow).

3) Airspace changes as part of the future airspace strategy

Any future flightpath decisions should directly consider the health implications of any proposed change including where the health burden will be, with a particular focus on vulnerable groups. This should consider evidence of the particular effects of a step change in noise exposure on annoyance and sleep disturbance.

Supplementary Recommendation 3: Future aviation policy decisions should assess the impact from aircraft noise on health, including undertaking health impact assessments where appropriate, and should ensure that health impacts are monetised to inform cost-benefit analyses.

Supplementary Recommendation 4: The Government should use its five yearly revisions of noise action plans and noise exposure maps to assess progress towards achieving its health-based noise targets for aviation.

LIST OF ACRONYMS AND ABBREVIATIONS

AEF – Aviation Environment Federation

AMI – Acute Myocardial Infarction (heart attack)

APF – Aviation Policy Framework

ATWP – Air Transport White Paper

CAA – Civil Aviation Authority

CI – Confidence Interval. A confidence interval is a range of values that describes the uncertainty surrounding an estimate, in this report for the odds ratio for the onset of a health effect

DALYs – Disability Adjusted Life Years

Defra – Department for Environment, Food and Rural Affairs

DfT – Department for Transport

END – Environmental Noise Directive. Directive: 2002/49/EC

ERCD – Environmental Research and Consultancy Department in the CAA

HYENA - Hypertension and Exposure to Noise near Airports study

IGCB(N) - Inter-departmental Group on Cost and Benefits for Noise

IHD – Ischaemic Heart Disease

NPPF – National Planning Policy Framework

NPS – National Policy Statement

NPSE – Noise Policy Statement for England

RANCH - Road traffic and Aircraft Noise Exposure and Children’s Health study

QALYs – Quality Adjusted Life Years

WHO – World Health Organisation

NOISE METRICS

Studies into the health effects of noise use a range of noise metrics. The most commonly used noise metrics are average noise metrics which average out all the peaks and troughs in noise over a certain period of time. These average noise contours are useful in assessing the long-term relationship between noise levels and a health outcome but they don't reflect how people actually experience noise as a series of peaks in noise levels associated with an event, such as a plane flying over, on top of background noise levels. Studies looking at impacts which occur as a result of a specific noise event are more likely to focus on single event noise metrics, such as Lmax.

dBA – Decibels, A-weighted. A decibel is the unit used to measure sound energy and the use of the A-weight reflects how noise is perceived on the human ear.

LDEN– Average weighted 24 hour noise where noise in the evening and at night are given more weight than daytime noise (by adding a 5 and 10 dB weighting to each event during those periods respectively)

LDN - The LDN measure is similar to the LDEN, in that it is an average weighted 24 hour noise metric but it omits the 5 dB penalty during the evening period

Leq – Average daytime noise, unweighted (typically 0700 – 2300)

Lnight – Eight hour average night noise, unweighted (typically 2300 – 0700)

Lmax – the peak noise level of an individual event

NNI - Noise and Number Index, the Government noise metric before Leq

SEL - Sound Exposure Level represents the duration and the magnitude of a noise event (i.e. how loud the noise is, and how long the noise lasts). The SEL metric measures all the sound energy over the entire event, usually 10 seconds, and does not directly reflect the sound level heard at any given time. SEL is often used to show the noise footprint of an individual aircraft in the form of a contour map.

INTRODUCTION

Noise from transport and industrial sources (referred to as environmental noise) is a widespread public health problem which leads to over one million years of healthy life lost each year across Western Europe (WHO Europe 2011). This makes it the second largest environmental risk to public health after particulate air pollution. Over two thirds of the UK population live in areas where noise levels are above the WHO guidelines designed to protect public health and wellbeing (Health Protection Agency 2010; WHO Europe 2009). However, the need to limit the effect of noise on health has largely been neglected in policies across Europe and in the UK. Unlike for air quality, there are no legally binding health-based national or European limits for noise, and the current EU noise policy requires only that member states introduce noise action plans with the aim of reducing noise, without providing any clear targets to meet (Defra 2010b).

Aircraft noise is a major component of environmental noise. It is associated with greater annoyance at the same noise levels than road or rail noise, and has impacts on cardiovascular health, sleep disturbance and children's memory and learning. New evidence in relation to health impacts is emerging each year with recent studies tending to look at effects on larger populations and to ensure that findings take account of other contributing factors (such as poor air quality and other noise sources). In addition, attitudes to noise are changing, with people increasingly unsatisfied with levels of noise around where they live (Health Protection Agency 2010).

The most recent nationally representative survey of public attitudes to noise by Defra, the UK Government's environment department, revealed that close to one third of those interviewed (31%) from a sample selected from across the UK were annoyed, disturbed or disrupted by aircraft noise levels where they lived, and 4% of those asked said their lives were severely disrupted by aircraft noise (Defra 2014b). These percentages were significantly higher than those in the previous survey, carried out in 2000.

Today's aircraft are individually much less noisy than previous generations of aircraft and the aviation industry is undoubtedly aware of the need to tackle aircraft noise if it is to be allowed to continue to expand. However, large numbers of people around the UK's major airports continue to live in areas where noise levels from aircraft are above the health-based WHO guidelines. According to research carried out for the Airports Commission, over one million people in the UK are exposed to aircraft noise levels above 55 dBA Lden, over 850,000 people live in areas of average daytime noise above 54 dBA Leq (16 hour) and 580,000 live in areas above 48 dBA Lnight (8 hour) (Jacobs 2014). However, noise exposure is not modelled all the way down to WHO night noise limits.

Due to a lack of data at the lower levels, it is not possible to say exactly the number of people whose health is potentially impacted by aircraft noise but the figures show that over one million people fall within 55 LDEN noise contours for airports, while Defra's nationally representative noise attitudes research suggests closer to two million people could be annoyed by aircraft noise. Many of the people affected by harmful levels of aircraft noise live around Heathrow Airport, with three times as many people living within its 55 dBA Lden (24 hour) noise contour than around Frankfurt, which has the second highest number of people exposed to noise at this level in Europe (Airports Commission 2013).

At present policy is lagging behind the evidence.

As the evidence mounts, it is increasingly possible to assess the burden on the health of a population from aircraft noise. It is also possible to consider the health impacts of noise in policy decision-making, including through the development of approaches that apply a monetary value to the health impacts on a population of a specific noise source. These methodologies mean that health impacts can be accounted for in cost-benefit analyses, and decisions can be made that better reflect the health burden of aircraft noise.

At present, however, policy is lagging behind the evidence. The Government's policy on aircraft noise retains the 57 dBA Leq average daytime noise contour as its only meaningful noise threshold to indicate of the onset of community annoyance, despite the figure being based on evidence dating back to the early 1980s. This has had knock-on effects for other areas of Government policy, such as how changes to airspace are made, such that they do not reflect the latest health-based evidence.

The recent work by the Airports Commission used the health costs of aircraft noise as the basis for two of the noise conditions recommended along with a new runway at Heathrow: a partial night flights ban and prioritising insulation of schools. Yet the wider question about the basis for judging whether expansion should proceed at an airport already exposing hundreds of thousands of people to noise above the maximum level recommended by WHO wasn't considered.

The evidence base is strong enough, this report argues, for all areas of aviation policy to be informed by health costs, and there is a need for targets to reduce the health burden of noise on communities around the UK's airports. The recent intervention in Parliament by the Aviation Minister, Robert Goodwill, about WHO guidelines highlights policy maker concerns with the existing guidelines:

"It is not possible to have a single objective noise-based measure that is applicable to all sources of noise in all situations because effect levels are likely to be different for different noise sources, different people and at different times. As such, the Government has no plans to introduce the World Health Organisation's guidelines for community noise." (Source: Hansard 2015)

This year, the Government will have an opportunity to reconsider its position when the WHO publishes its new community noise guidelines, based on the wealth of evidence that has emerged over the past 16 years for daytime noise and six years for night noise, as illustrated in this report. The new guidelines are, in particular, expected to facilitate the setting of targets for specific noise sources. The Government will also have several key decisions to make over the next 12 months which could have profound implications for public health, including the final decision on a new runway in the South East of England, setting new airspace policy and updating the regulations for night noise around the major London airports.

This year, the Government will have an opportunity to reconsider its position when the WHO publishes its new community noise guidelines.

This report provides clear recommendations for the Government to ensure that the health impacts of aircraft noise are better integrated in policy making and highlights the imperative for an overarching Government policy to reduce the health burden from noise. The report is split into two parts: part one summarises the latest evidence on the health impacts of aircraft noise, and part two looks at whether policies have kept up with the developing evidence base, including a consideration of the most widely used methodologies for monetising the health impacts of aircraft noise. Finally this report sets out recommendations for how Government policy could better take account of health impacts.

PART ONE: THE EVIDENCE

A LITERATURE REVIEW OF THE HEALTH IMPACTS OF AIRCRAFT NOISE

1.1 KEY ISSUES

Major academic studies have concluded that exposure to environmental noise above certain levels has negative health outcomes (see for example Basner et al. 2014; Health Protection Agency 2010; WHO Europe 2009). This review looks at the strength of evidence underlying the main health effects associated with aircraft noise, focusing on five topics, namely cardiovascular disease, sleep disturbance, annoyance, impairment of learning and memory in children, and links to long-term mental health.

All of these impacts warrant attention given the strength of the evidence, the extent of the impacts, and community concerns.

All of these impacts warrant attention given the strength of the evidence, the extent of the impacts, and community concerns. The large scale German NORAH study, which was initiated by the airport and community forum associated with Frankfurt Airport, recently looked at many of these effects, as have other reviews of the health impacts of environmental noise (see for example Clark 2015). All comply with the World Health Organisation (WHO) definition of health as:

"A state of complete physical, mental and social well-being and not merely the absence of disease or infirmity, and recognizes the enjoyment of the highest attainable standard of health as one of the fundamental rights of every human being" (WHO Europe 2009, p.VII).

The evidence base for noise and health considers how people respond to specific noise events, which is relevant for sleep disturbance, next day and short-term impacts such as annoyance, and long-term effects (such as cardiovascular illness). Some of the short term effects, including annoyance and sleep disturbance are considered as being likely to increase the risk of long term health effects, known as an 'impact pathway' (see figure 1).

Assessing the strength of evidence

For each of the impacts considered, this review examines the strength of the relationship between noise and a given health effect using the WHO's approach, which can be broadly divided into three categories, outlined below (see WHO Europe 2009 for more information). The strength of evidence stated for each impact is based on assessments made in other reviews, informed by: the level of understanding of the extent of the effects; whether a causal association is consistent with existing biological

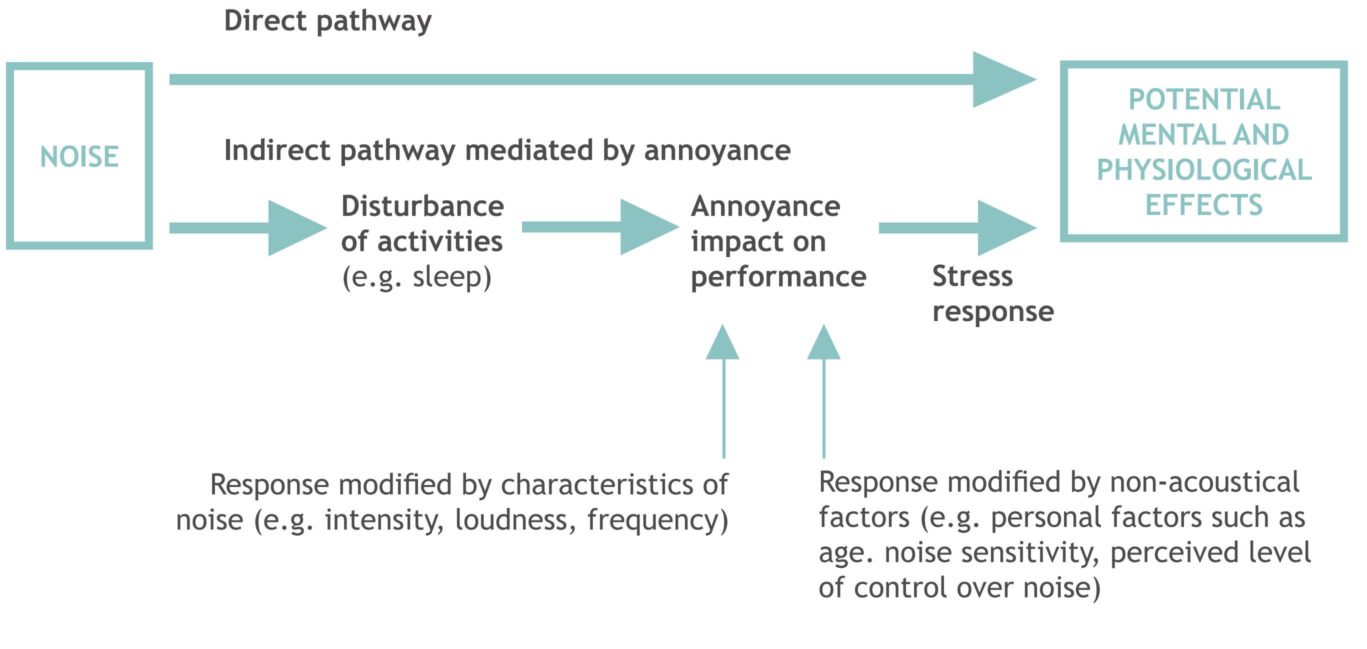

Figure 1: The range of health impacts from aircraft noise and the causal pathways between effects. Source: WHO Europe 2011

and medical knowledge (biological plausibility); the consistency of findings across different methodologies; and observation of an exposure-response relationship (explained below). On this basis, the strength of evidence for each health effect examined is described in a box at the end of each section as one of the following:

1. **SUFFICIENT** – There is clear evidence of a causal relationship and biological plausibility is well established.

2. **LIMITED** – A relationship has not been observed directly but the available evidence supports a conclusion that there is a causal relationship. Indirect evidence is abundant, linking noise exposure to an intermediate effect of physiological changes that could lead to adverse health effects.

3. **INSUFFICIENT** – The available studies are of low quality or lack the necessary statistical significance to allow a conclusion about causality of the relationship between exposure and effect.

Key challenges for assessing the strength of evidence

Exposure - response relationships

An exposure – response relationship (also referred to as a dose-response relationship) indicates how much the risk of a given health impact increases with specific noise levels (Berry and Sanchez 2013). The work by Berry and Flindell (2009) carried out for Defra was focused on exposure-response relationships, and identified uncertainties for certain effects. This continues to be an area where future research is needed (ENNAH 2013). However, in cases where the exposure-response relationship is well-evidenced and information is available on the extent of noise exposure, it is possible to calculate the risk in a certain population associated with the noise exposure. This then allows a monetary cost to be applied to the extent of the health impact across a population (EEA 2010).

For each impact, the most widely accepted dose-response relationship is set out where it exists and the limitations and uncertainties are discussed. An exposure-response relationship is usually defined as an 'odds ratio', which provides a figure for how much the risk of a health effect will change depending on the level of noise. A 95% confidence interval (CI) is a statistical term often stated alongside the odds ratio. When there is a wide confidence interval, it indicates there is high uncertainty in the odds ratio produced from a study or review.

Thresholds

Thresholds of noise levels exist for some of the health impacts below which no impact is seen (WHO 1999a). The WHO's guidelines – both the community guidelines from 1999 and the WHO Europe's night noise guidelines from 2009 – focus on the level of exposure for the lowest observed adverse effects, i.e. the lowest noise level which can damage health. For each of the impacts considered in this review, a threshold is provided for the onset of the effect where it exists.

Confounding factors (other potential causes of the health effect)

Confounding factors make it harder to attribute noise levels to an effect by providing an alternative explanation for the observed association between noise exposure and an effect. This is particularly relevant for cardiovascular disease for which risks vary depending on socioeconomic status, exposure to noise from other sources, and local air quality. However, more recent studies tend to take these other factors into account and a review by Stansfeld (2015) of 25 studies that look at both noise and air pollution found independent, substantial effects of noise on cardiovascular outcomes. Certain confounding factors relate to individuals, such as smoking history, and studies directly looking at individuals tend to take these factors into account.

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Evidence for aircraft noise

WHO (1999a) noted that different noise sources have different "information content" which could affect thresholds and dose-response relationships. Aircraft noise is characterised by high noise levels per event but low numbers of events compared, for example, to road traffic noise (WHO 2009). Reviews of evidence on aircraft noise by the CAA in 2013 for the Department for Transport, and Dr Charlotte Clark in 2015 for the Airports Commission both highlighted strong links specifically between aircraft noise and health effects. Helicopter noise has different noise characteristics to aircraft noise, which this report focuses on, and so the evidence discussed is unlikely to be appropriate to predict the response to a helicopter noise event. The CAA also highlights the need to put weight on UK-based research due to the subjective nature of annoyance which may vary from one country to another (CAA 2013b).

The following selective review considers aviation-specific and UK-based research for each impact where it is available. For each impact, the extent of the problem is considered in terms of the size of the population which could be affected. The review first looks at cardiovascular impacts as the area where the most research has been carried out in recent years, before then looking at established effects of sleep disturbance and annoyance and the impact on children's learning, before examining effects on long-term mental health. This is not intended to be an exhaustive review of studies linking noise and health but a summary of the most relevant evidence.

1.2 CARDIOVASCULAR IMPACTS

The theory

Cardiovascular diseases are a major health problem in the UK, and one of the major causes of premature death. There is a clear biological pathway between noise exposure and cardiovascular disease.

A noise event places the body under stress. The body may then react consciously, following an 'emotional pathway' (such as through annoyance), or unconsciously (known as the direct response) where the central hearing and nervous systems interact, even though the person may be unaware (Basner et al 2014). In both cases the body reacts through the 'stress mechanism' to prepare the person to cope with a stressor, in this case noise. This involves changes in the body, such as making the nervous system and endocrine system active, releasing hormones, which increase heart rate and blood pressure (WHO Europe 2009).

Following this theory, long-term exposure to noise contributes to an imbalance in an individual's metabolism, leading to increases in risk factors associated with cardiovascular disease such as higher blood pressure and increased concentration of blood lipids (Basner et al. 2014). Hypertension is a condition in which blood vessels have persistently raised pressure, putting them under increased stress. Many people with hypertension have no symptoms, but raised blood pressure increases the risk of damage to the heart and blood vessels in major organs such as the brain and kidneys. This can lead to ischaemic heart disease (IHD), which occurs when the heart's blood supply is blocked or interrupted

Babisch (2014) concluded that "the question is no longer whether noise causes cardiovascular diseases; it is rather to what extent."

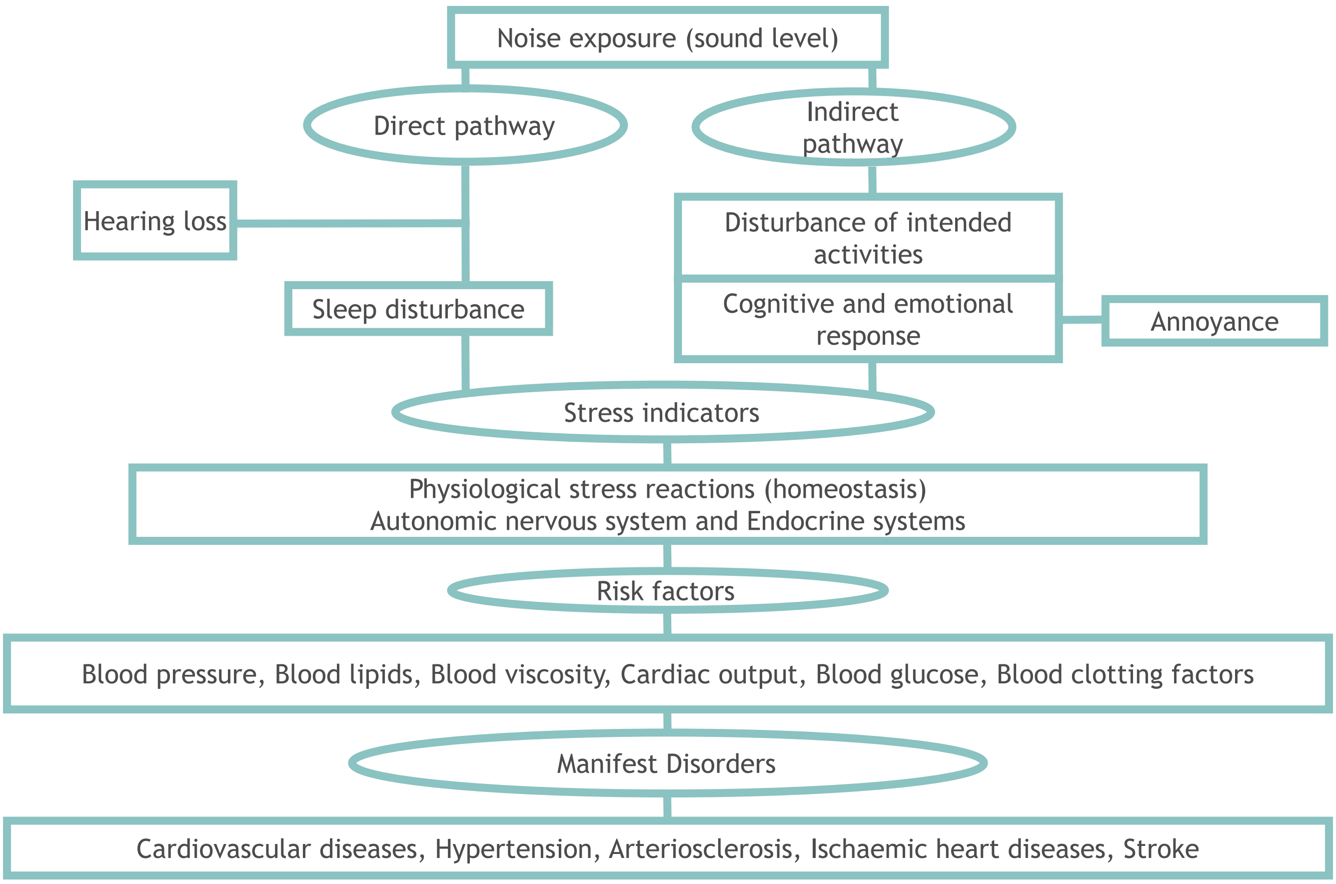


Figure 2: A flow chart outlines the effect pathway for cardiovascular impacts of aircraft noise. Source: Babisch (2006)

by a build-up of fatty substances in the coronary arteries, and ultimately heart attack (known as Acute Myocardial Infarction (AMI)), and stroke (WHO 2011). Raised blood pressure is also considered a major risk factor for dementia and kidney failure.

Harding et al. (2011) considered the increased risk of heart attack, stroke and dementia from hypertension to be the most important cardiovascular health outcomes due to the strength of evidence and prevalence of these illnesses across the UK population. The noise studies discussed below tend to focus on these health outcomes. It is likely that both sleep disturbance and annoyance, both discussed later, may contribute to long-term cardiovascular disease (Harding et al. 2011).

Strength of the evidence

Long-term exposure to aircraft noise is associated with increased risk of hypertension (high blood pressure), along with cardiovascular diseases including heart disease, heart attacks, stroke and dementia (Basner et al. 2014). A number of studies have been carried out over the last 10 years looking at large populations, which have strengthened the evidence base for cardiovascular health impacts (Stansfeld 2015). Babisch (2014) concluded that "the question is no longer whether noise causes cardiovascular diseases; it is rather to what extent" (page 1).

Hypertension

There is evidence specifically linking aircraft noise and hypertension, and WHO views the evidence as SUFFICIENT (WHO Europe 2011). A review by Babisch and van Kemp (2009) developed a dose-response relationship for the increased risk of hypertension where it increases by 13% (95% confidence interval (CI) 0-28%) per 10 dBA LDN increase in aircraft noise between 45-70 dBA LDN, with an onset threshold of 50 dBA. It should be noted, however, that Babisch and van Kemp identify limitations with their proposed dose-response relationship, particularly due to differences in the methods used to assess exposure and health outcomes between the studies reviewed.

The HYENA (Hypertension and Exposure to Noise near Airports) study was a high quality and large-scale research project with the aim of assessing the relationships between aircraft

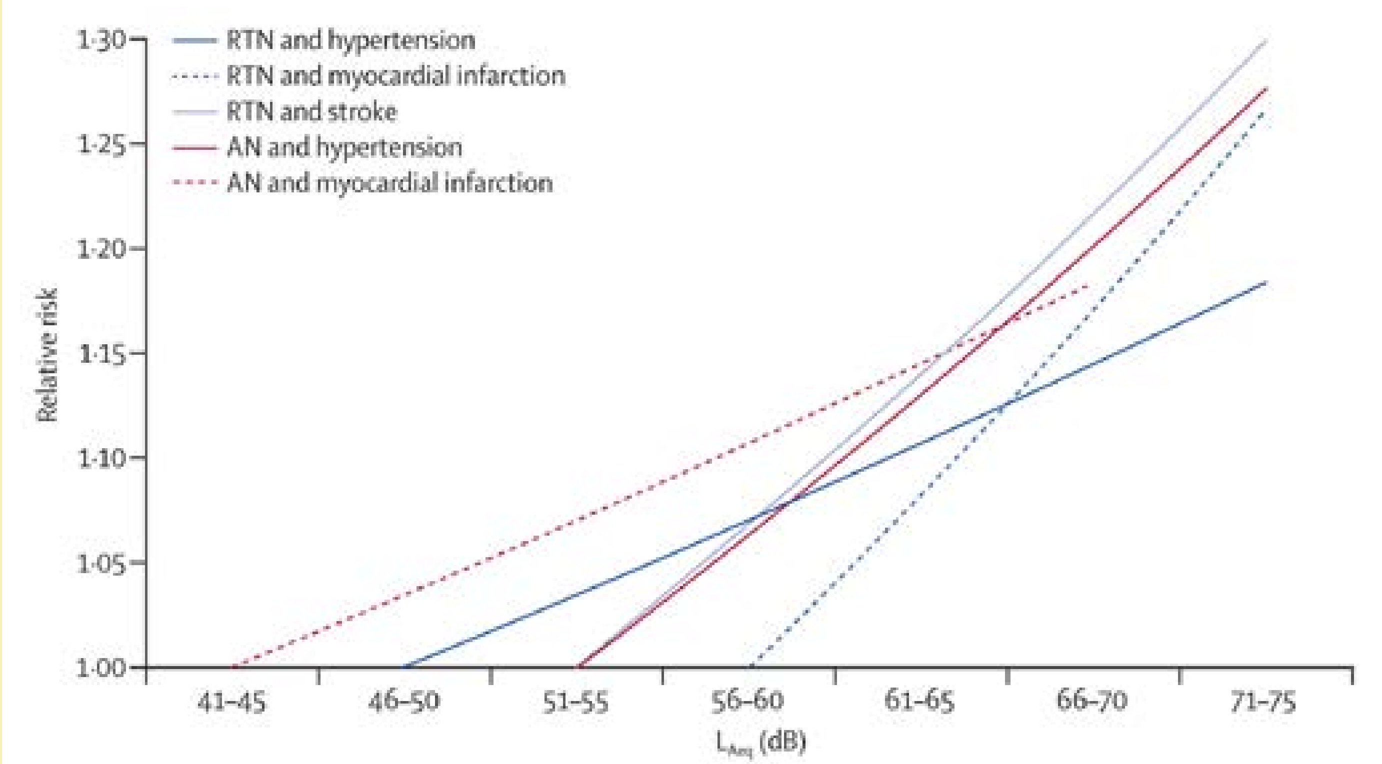


Figure 3: Dose-response relationships for road traffic (RTN) and aircraft (AN) noise and cardiovascular diseases. Source: Basner et al. 2014
RTN and hypertension (24 studies, noise indicator LAeq16h); RTN and myocardial infarction (five studies, noise indicator LAeq16h); RTN and stroke (one study, noise indicator LDEN); AN and hypertension (five studies, noise indicator LDN); and AN and MI (one study, noise indicator LDN)

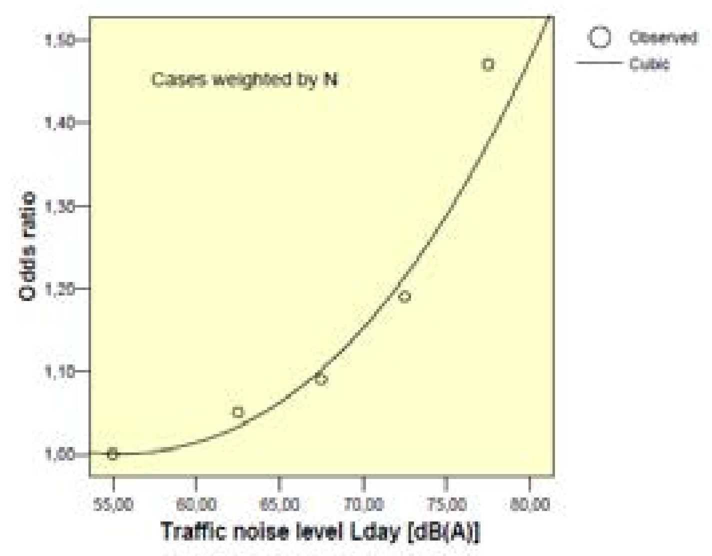


Figure 4: The Babisch dose-response curve for transport noise and Acute Myocardial Infarction. Note the use of the Lday 12 hour metric, rather than 16 hour as used for aircraft noise. Source: Babisch 2006

and road traffic noise exposure and the risk of hypertension. The HYENA study included a population sample around Heathrow Airport. Based on the HYENA study, Jarup et al. (2008) identified a significant relationship between night-time aircraft noise and hypertension. For a 10 dBA increase in aircraft noise at night (Lnight, 8 hour), there was a 14% (95% confidence interval (CI), 1.01–1.29) increase in the probability of high blood pressure. However, the research found no significant relationship for daytime noise. Research by Floud et al. (2011) found a 10 dBA increase in night-time aircraft noise was associated with a 34% (95% CI 14 to 57%) increase in the use of medication for high blood pressure in the UK. This suggests there is a clearer relationship between night-time aircraft noise and increased hypertension than for daytime noise.

A 2007 study comparing noise exposure under different runways at Frankfurt airport identified that the community with higher average noise levels had higher average blood pressure (CAA 2013b). However, the recently published findings from the large-scale German-based NORAH study identified no significant effects from average night-time aircraft noise on the blood pressure of 800 participants (NORAH 2015). This conflicts with the findings of other studies and indicates that there are still uncertainties in the relationship.

Cardiovascular disease

Work by Harding et al. (2011) for the Health and Safety Laboratory, part of the UK non-departmental public body the Health and Safety Executive, assessed the impact of increased rates of hypertension from higher environmental noise levels on the risk of heart attack (as an end point of ischaemic heart disease), stroke and dementia, as the key health outcomes related to hypertension (discussed above). This work is particularly useful for assessing the cardiovascular impacts on populations from specific noise sources because it was UK-based. The study assessed the increased risk of the health outcomes associated with increased hypertension cases and then related that to the relationship between noise and hypertension set out by Babisch and van Kemp (2009).

Direct dose-response relationships linking these health outcomes with environmental or aircraft noise have been developed based on large scale population studies, and meta-analyses which involve bringing data together from multiple studies to create statistically stronger relationships. A review of cardiovascular disease meta-analyses for road and aircraft noise by Basner et al. (2014) set out in figure 3. While the evidence clearly identifies increased risk of cardiovascular issues, the exact relationship is not clear.

For the link between noise and heart attack, a key study by Babisch (2006) produced a dose–response curve for road traffic noise (see figure 4). Use of the Babisch curve has been recommended for aircraft noise in the absence of a source-specific curve, despite there being some uncertainties in it (Berry and Flindell 2009; WHO 2011). The Babisch curve indicates that below daytime road traffic sound levels of 60 dBA Lday 12 hour (0700 - 1900), no increase in AMI risk could be detected. For noise levels above 60 Lday, the AMI risk increases continuously, with the odds ratio ranging from 1.1 to 1.5, with reference to a baseline of ≤60 Lday, as identified in the below graph.

A key UK-based study by Hansell et al. (2013) found that high levels of aircraft noise were associated with increased risk of stroke, coronary heart disease, and cardiovascular disease. These estimates remained significant after taking into account air pollution, age, sex, ethnicity, deprivation and lung cancer mortality as a proxy for smoking.

Studies focusing on aircraft noise have found significant relationships for increased risk of heart attack. For example, a Swiss study by Huss et al. (2010) looking at mortality from heart attacks and aircraft noise for 4.6 million residents, found that mortality from heart attacks increased with greater exposure to aircraft noise, particularly when an individual had been exposed for long period of time (over 15 years). The recent large-scale NORAH (2015) study in Germany found statistically significant associations for aircraft noise and heart attack.

A key UK-based study by Hansell et al. (2013) found that high levels of aircraft noise were associated with increased risk of stroke, coronary heart disease, and cardiovascular disease for both hospital admissions and mortality in areas near Heathrow airport. The study looked at 12 London boroughs and nine districts in West London, covering 3.6 million people. It found that compared to people exposed to daytime aircraft noise levels below 51 dBA Leq, those exposed to aircraft noise levels over 63 dBA Leq had a 24% higher chance of a hospital admission for stroke (with 95% CI of 8% - 43% increased risk); a 21% higher chance of a hospital admission for coronary heart disease (CI: 12% - 31%); and a 14% higher chance of a hospital admission for cardiovascular disease (CI: 12% - 31%). No difference could be distinguished for night noise compared to day noise. These estimates remained significant after taking into account air pollution, age, sex, ethnicity, deprivation and lung cancer mortality as a proxy for smoking.

The findings of the Hansell et al. (2013) study have been supported by other recent aircraft noise specific studies including by Corriera et al. (2013) from the United States and Evrad et al. (2014) from France. Corriera et al. (2013) looked at the occurrence of cardiovascular diseases in six million older people near 89 airports and found a 3.5% increase in risk of cardiovascular disease per 10 dBA increase in aircraft noise, above 55 dBA LDN, accounting for confounding factors, including air pollution and road noise.

The CAA described the results as statistically powerful, given the number of people in the study, but were critical about the fact that the research did not differentiate day and night-time exposure, and did not control for smoking (CAA 2014). The study by Evrad et al. (2014) looked at aircraft noise and cardiovascular outcomes among 1.9 million people around Paris Charles de Gaulle, Lyon Saint Exipey, and Toulouse-Blagna airports. The study found significant positive associations between increases in aircraft noise and mortality from cardiovascular disease, heart disease, heart attack, and – to a lesser extent – stroke, after accounting for air pollution.

Not all studies are in agreement, however. The Huss et al. (2010) study did not find significant links between aircraft noise exposure and other cardiovascular outcomes such as stroke or heart disease, and the NORAH study found a significant relationship for stroke and aircraft noise only when the Lmax noise metric was used for night noise (NORAH 2015). Floud et al. (2013) found statistically significant results based on the HYENA study for self-reported heart disease and stroke as a result of night aircraft noise exposure

The increased risk between aircraft noise exposure and heart and circulatory illnesses is thought to be moderate but it has importance for public health when large populations are exposed.

only when individuals were exposed to aircraft noise for 20 years or more. For people exposed in the long-term to aircraft noise, Floud et al. (2013) found the risk of heart disease increased by 25% (3-51%) per 10 dBA increase in night noise (Lnight)).

Emerging research area: obesity and diabetes

In the past, obesity and diabetes have been considered as confounding factors rather than possible outcomes of noise exposure but the PARTNER project from the U.S. called for research into whether noise may increase the risk of both these health effects (Swift 2010). The imbalance in the stress regulatory mechanism associated with increased noise levels may, it was hypothesised, lead to alterations in tissue metabolism and obesity and type II diabetes. Sleep disturbance is also known to disrupt metabolic and hormone functions, which could increase the risk. A recent Swedish study by Eriksson et al. (2014) investigated the relationship between aircraft noise and both obesity and diabetes, finding that exposure was associated with a larger waist circumference but less clearly with type II diabetes and increased Body Mass Index. The study followed participants for 10 years and found that a 5 dBA LDEN increase in aircraft noise was associated with an increase in waist circumference of 1.51cm (CI: 1.13-1.89). The relationship was particularly strong when the participant didn't move house during the assessment period. The study adjusted for individual-level factors including diet and alcohol consumption.

Scale of the problem in the UK

The increased risk of heart and circulatory illnesses posed by aircraft noise exposure is thought to be moderate but it has importance for public health when large populations are exposed, particularly because there is increased risk of death from heart attacks (Clark 2015). Over one million people in the UK are exposed to aircraft noise above 55 LDEN, which is above the onset threshold for increased rates of long-term high blood pressure (Babisch and van Kemp 2009).

Evidence summary for cardiovascular effects of aircraft noise

Thresholds: For hypertension, Babisch and van Kemp (2009) indicate there is no recorded risk below 50dBA LDEN.

Dose-response:

- Babisch and van Kemp (2009) identify a relative risk increase for hypertension of 1.13 per 10 dBA increase above 50 dBA LDEN.
- For risk of heart attack, the dose-response curve set out by Babisch in 2006 indicates the most accepted relationship, where for noise levels greater than 60 dBA Lday 12 hour, the heart attack risk increases continuously, with relative risks (odds ratios) ranging from 1.1 to 1.5.
- Harding et al. 2011 developed a dose-response relationship for increased risk of stroke and dementia as a result of noise-induced hypertension. This dose-response relationship can be used to indirectly calculate the increased risk of stroke and dementia and it is being used by Defra.

Evidence strength:
There is SUFFICIENT evidence to demonstrate that higher levels of aircraft noise do increase the risk of cardiovascular disease (Basner et al. 2014; Clark 2015; WHO Europe 2009). However, the cardiovascular effects of aircraft noise are not clear-cut and dose-response relationships cannot be regarded as definitive. The direct evidence for certain impacts including stroke and dementia appears LIMITED.

Research needs:
Develop long-term studies which revisit participants at different periods of time to look at the changing long term impact (ENNAH 2013). There is also a need to develop aviation specific dose-response relationships for each health outcome and to strengthen the hypertension dose-response relationship.

1.3 SLEEP DISTURBANCE

The theory

Sleep disturbance from environmental noise is a major concern for public health, as undisturbed sleep over a sufficient number of hours is needed for alertness and performance and for health and quality of life (Basner et al., 2014). An eight hour period (usually 11pm-7am) is often used to define the night-time period. Chronic sleep disturbance is regarded as a health effect in its own right with a measurable impact on quality of life (DfT 2013b), even though it does not directly lead to premature death. There are uncertainties, however, over how much impact it has on quality of life which has meant large variability in the estimates of the effects on health of a population. The U.S. Federal Aviation Authority noise research roadmap identifies sleep disturbance as a priority research area.

Sleep disturbance during the early part of night and early morning prior to natural awakening is thought to be most intrusive.

Self-reported sleep disturbance is the easiest method of assessing sleep disturbance, but humans exposed to sound whilst asleep have unconscious physiological reactions including changes in breathing, body movements, and heart rate, in addition to effects such as early awakenings, delayed sleep onset and increasing time awake (Basner et al. 2014). This is the direct response discussed in the cardiovascular section. An aircraft noise event can influence the time spent in different sleep stages, which impacts quality of sleep by reducing the time spent in Rapid Eye Movement (REM), the restorative part of the sleep cycle (Clark 2015). This has relevance for early morning flights because more time is spent in REM sleep during the later parts of the night (Clark 2015).

WHO has argued that the probability of awakening increases with the number of events and with increased in the sound levels of individual events. To account for this, it recommends using exposure noise metrics that monitor individual events (such as Lmax).

Sleep disturbance during the early part of night and early morning prior to natural awakening is thought to be most intrusive (CAA 2013b). Aircraft noise exposure outside this period during evening and early morning has relevance for children, the physically ill, and shift workers (Clark 2015). Few studies have specifically looked at sleep disturbance in children (Stansfeld and Clark 2015).

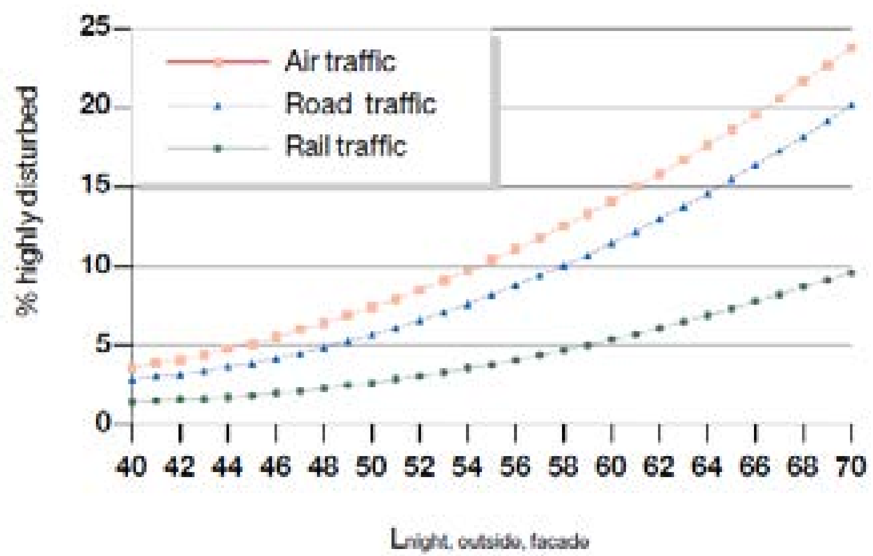


Figure 5: Dose-response relationships for transport noise sources and % of the population highly sleep disturbed. Source: WHO Europe 2009

WHO has argued that the probability of awakening increases with the number of events and with increased sound levels of individual events. To account for this, it recommends using exposure noise metrics that monitor individual events (such as Lmax) as well as average exposure metrics (such as Lnight) (WHO Europe 2009). Leipzig/Halle airport in Germany introduced noise policy that explicitly sets out to limit the number of additional awakenings induced by aircraft noise, and Zurich and Frankfurt also introduced the use of noise metrics that monitor night-time aircraft noise in terms of the total number of awakening reactions elicited (Hume et al. 2012).

Impacts also depend on the acoustic properties of the noise source and individual noise susceptibility (Basner et al. 2014). Aircraft and rail noise are seen as more disturbing for sleep subjectively than road traffic noise, but road traffic noise has been associated more clearly with changes in sleep structure (CAA 2013b). It is therefore recommended that there are different sleep disturbance dose-response curves for different transport modes (WHO Europe 2011).

Strength of the evidence

There is SUFFICIENT evidence from community-based studies to demonstrate that night-time aircraft noise exposure leads to sleep disturbance, including changes in heart rate, arousals, sleep stage changes and awakening (Hume et al., 2012; Berry and Flindell 2009; WHO Europe 2009). WHO has argued that average night noise should not exceed 40 dBA (Lnight, 8 hour) to protect public health, including vulnerable populations (WHO Europe 2009).

Physiological reactions (such as increases in blood pressure or heart rate) may occur for individual noise events as low as 33dB (Basner et al. 2014). A meta-analysis of 24 studies, including nearly 23,000 individuals exposed to night-time noise levels ranging from 45-65dBA, found that aircraft noise was associated with greater self-reported sleep disturbance than road traffic noise at comparable levels (Miedema & Vos, 2007). The most widely accepted dose-response curve for aircraft noise and sleep disturbance is the curve developed by Miedema from 2003 and used by the European Commission (see figure 5). The curve estimates the percentage of a population that would be highly sleep disturbed from a given level of aircraft, road or rail noise. There are limitations in relation to this curve since it is based on self-reported sleep disturbance and there is uncertainty over how universally applicable it is (Sanchez et al. 2014).

A meta-analysis of 24 studies, including nearly 23,000 individuals exposed to night-time noise levels ranging from 45-65dBA, found that aircraft noise was associated with greater self-reported sleep disturbance than road traffic noise.

The recent German-based NORAH study examined the effect on sleep disturbance of the introduction of a partial night flights ban (11pm-5am) at Frankfurt Airport following the opening of a new runway in 2011 (NORAH 2015). The study looked at sleep disturbance for 200 people using electrodes in 2011, before the new runway was opened (and so before the night flights ban was operational), and in 2012 and 2013 after the runway and core night flights ban were in operation. The study found that after the core night flights ban was introduced, residents near the airport woke up less frequently at night but sleep was more disturbed after 5am. The actual study followed laboratory assessments of what the Frankfurt night flights ban could mean for sleep disturbance which had suggested improved sleep over the night ban period but that the benefits for sleep would be offset by increases in noise before and after the ban if flights were rescheduled (Clark 2015).

Sleep disturbance also has secondary effects the day after, such as reduced performance (WHO Europe 2009). Defra estimated the cost to productivity of noise is up to £6 billion per year, based on work by the Transport and Research Lab (Defra 2014). A study in 2008 found that the loss to UK productivity of sleep disturbance (not just noise-related) is around 3.5 days absence from work per employee each year, costing an estimated €1,010 per employee per year (Airports Commission 2013). This is an area for monetising the health impacts of aircraft noise that Defra believe needs development (Defra 2014).

Sleep disturbance is also associated with long term health impacts. Observational and experimental studies indicate that the stress response impact of sleep disturbance may lead to hypertension (Schmidt et al. 2013). Habitual short sleep of less than 6 hours is associated with obesity, diabetes, and cardiovascular disease (Munzel et al. 2013). There are, however, uncertainties about the extent to which sleep disturbance results in long-term effects (Berry and Flindell 2009). Munzel et al. (2014) calls for a large study measuring noise-induced sleep disturbance in a cohort of participants for several years.

WHO highlights that a substantial part of the EU population is exposed to night noise levels that risk health and well-being (WHO Europe 2009).

Scale of the problem in the UK

The UK Government acknowledges that aircraft noise at night is widely regarded as the least acceptable aspect of aircraft operations (DfT 2013b). WHO highlights that a substantial part of the EU population is exposed to night noise levels that risk health and well-being (WHO Europe 2009). Around 580,000 live in areas above 48 Lnight (8 hour) at night around the UK's major airports according to analysis for the Airports Commission (Jacobs 2014). An even greater number of people are exposed to aircraft noise levels at night above the WHO recommended level, as discussed below, but the CAA currently doesn't produce maps that measure noise levels down to the WHO target.

Evidence summary for sleep disturbance

Threshold
WHO has identified that only above 40 dBA Lnight are adverse health effects observed among the exposed population. Above 55 dBA Lnight adverse health effects occur frequently, and a sizable proportion of the population is highly annoyed and sleep-disturbed (WHO Europe 2009).

Dose-response
The most authoritative dose-response analysis is the Miedema curve used by the European Commission and WHO Europe (Defra 2010b).

Evidence summary
SUFFICIENT (WHO Europe 2009)

Research needs
There is a need to assess the long-term effects of sleep disturbance (Berry and Flindell 2009). There is also a need to examine uncertainties related to the Miedema dose-response curve.

1.4 ANNOYANCE

The theory

Annoyance is the most commonly used means to evaluate the effect of noise on communities (Airports Commission 2013). It is a complicated psychological concept which increases with noise exposure, changes to pitch and the regularity of being exposed to noise (Berry and Flindell 2009). Non-acoustical factors are important in contributing to annoyance, including whether the person is able to control the intrusion, and their personal attitude to the noise source (WHO Europe 2011). This means that individuals react to noise differently and reactions depend on the context. It is also the reason why noise is often considered to be a subjective issue. However, annoyance can interfere with daily activities leading to stress-related symptoms, with severe effects on well-being and health (Basner et al. 2014).

Annoyance can interfere with daily activities leading to stress-related symptoms, with severe effects on well-being and health.

Dose-response curves exist which provide estimates for the likely percentage of the population annoyed by individual noise sources. These are based on large-scale surveys, where people answer standardised questions about their long-term annoyance from particular noise sources by giving a rating between “not at all annoyed” and “extremely annoyed” (Clark 2015).

The focus for deriving dose-response curves tends to be to assess the proportions of a population annoyed and highly annoyed for a certain noise level. Major studies in the UK and worldwide have concluded that aircraft noise is associated with a stronger annoyance response than road traffic noise at the same average level (WHO 1999a) and that annoyance is increasing even as individual aircraft become quieter.

Strength of evidence

There is SUFFICIENT evidence linking aircraft noise and annoyance (Berry and Flindell 2009). The dose-response curve initially developed

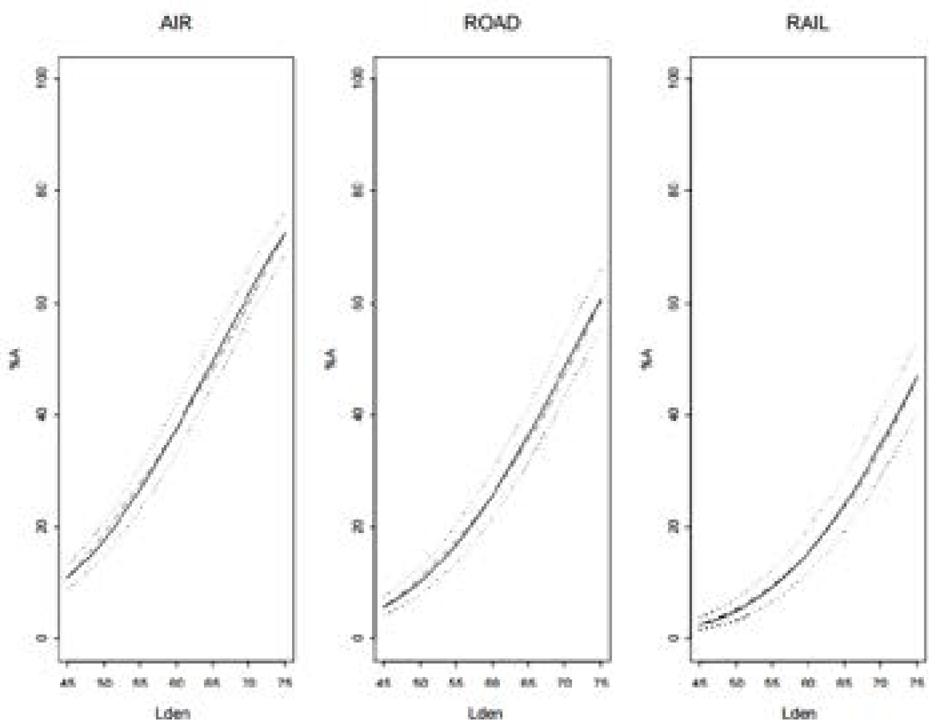


Figure 6: Dose-response curves for transport noise sources (Lden) and % of the population annoyed. Source: EC 2002

by Schultz in 1978 set out the proportion of a population highly annoyed at certain noise levels (LDN) and informed government policy, particularly in the U.S. (it is still used by the FAA).

There is concern that reaction to sudden changes in noise exposure cannot be predicted by dose-response functions under steady state conditions, particularly where populations experience a significant increase in exposure, and in response to evening and early morning flights.

Miedema identified an updated dose-response curve for annoyance from different transport noise sources, which informed EU policy (see EC 2002). There remain limitations to this dose-response curve, however, due to the nature of annoyance. For example, it is unlikely to be reflective of annoyance in all situations (Sanchez et al. 2014). It is, however, the most widely used dose-response curve in EU noise policy.

In the UK, the Government carried out the ANIS research (Aircraft Noise Index Study) in the early 1980s, which found that respondents to its survey were broadly in line with the Schultz curve. At the time, the official UK aircraft noise metric was the Noise and Number Index (NNI). In the 1990s, the UK changed the official metric from NNI to the current metric for average daytime noise, Leq 16 hour. Mapping the ANIS study across from NNI to Leq showed that respondents were significantly annoyed by aircraft noise above 57 dBA leading the Government to conclude that the 57 Leq noise contour marked the onset of significant community annoyance (see the policy section for more on this).

The findings of ANASE showed that a greater percentage of people are highly annoyed by aircraft noise at any given level when compared to the previous study.

In the 2000s, the Government carried out research intended to update its understanding of community annoyance from aircraft noise. The main findings of this study, known as ANASE (Attitudes to Noise from Aviation Sources in England), were that people were significantly annoyed at noise levels below the 57 Leq noise contour, indicating an increase in noise annoyance around airports despite aircraft being individually quieter.

The findings of ANASE showed that a greater percentage of people are highly annoyed by aircraft noise at any given level when compared to the previous ANIS study undertaken in 1982 (and published in 1985). According to the results, the threshold of significant annoyance 57 Leq (16 hour) would lower to 50 Leq (16 hour) based on an equivalent percentage of the population being highly annoyed today. ANASE also confirmed many longstanding community concerns, namely that annoyance is strongly influenced by the number of noise events, and that aircraft noise at night is more annoying. Despite this evidence, the Government opted to retain the 57 Leq (16 hour) threshold.

The recent large-scale NORAH study around Frankfurt Airport found that residents were more disturbed by aircraft noise at the same average noise levels than in previous studies, above the European curve (NORAH 2015). This finding was echoed in studies at comparison airports (Cologne/Bonn and Stuttgart). A European-wide assessment by the European Network on Noise and Health (ENNAH), a network of expert noise and health academics from across the EU, similarly highlighted a need to update the aircraft noise and annoyance exposure relationship curve (ENNAH 2013).

There is also concern that reaction to sudden changes in noise exposure cannot be predicted by dose-response functions under steady state conditions, particularly where populations experience a significant increase in exposure, and in response to evening and early morning flights (Schreckenberg et al. 2011). A study around Zurich airport, published in 2008, indicated that increases in early morning and late evening flights were associated with over-reaction of annoyance (i.e. greater than expected for the noise level) (Clark 2015).

This finding is supported by the recent NORAH study which surveyed annoyance around Frankfurt airport in 2011, before a new runway was built, and again in 2012 and 2013. The study found that the greatest annoyance response was experienced in 2012, just after the new runway came into effect, and although respondents were slightly less annoyed in 2013, the response was still higher than the 2011 survey. The NORAH academics refer to the additional response above that predicted from traditional dose-response curves as the "change effect" (NORAH 2015).

One in three people interviewed for Defra's most recent, nationally representative, noise attitudes survey stated that they were moderately annoyed, disturbed or disrupted by aircraft noise levels where they live.

Background noise level is thought to be a key factor in community response to aircraft. A study in the US developed an aircraft noise dose-response relationship for national parks which revealed that overflight in tranquil areas, particularly national parks, led to greater annoyance (Anderson et al. 2011). This is also considered in section 1.6.

Scale of the problem in the UK

Significant numbers of people are disturbed by environmental noise. One in three people interviewed for Defra's most recent, nationally representative, noise attitudes survey stated that they were moderately annoyed, disturbed or disrupted by aircraft noise levels where they live, and 4% of people had their lives significantly disrupted (double the figure from the previous survey in 2000) (Defra 2014b). Given that Defra's survey was nationally representative, its findings suggest that as many as 2 million people could be significantly disturbed by aircraft noise. Over one million people in the UK are exposed to aircraft noise of above 55 dBA LDEN, the threshold used by the EU for noise mapping. This compares to 363,450 who are exposed to aircraft noise above the current Government definition of the onset of significant community annoyance (Jacobs 2014).

Evidence summary for annoyance

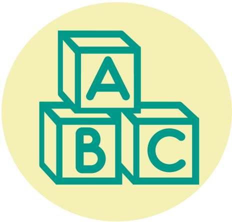
Thresholds
WHO (1999a) assessed that during daytime, few people would be highly annoyed below 55 dBA Leq (16 hour) and few people moderately annoyed below 50 dBA Leq (16 hour), and that the thresholds would be 5-10 dBA lower at night.

Exposure-response relationship
EU noise annoyance curves remain the best available evidence though they need to be updated and may not predict community annoyance responses to a step change in noise exposure.

Strength of evidence
SUFFICIENT (Berry and Flindell 2009)

Research needs:
To improve monitoring of annoyance responses to changes in aircraft noise exposure and aircraft operations (Clark 2015)

1.5 MEMORY AND LEARNING IN CHILDREN



The theory

Children are thought to be particularly vulnerable to noise as they are still developing physically and cognitively (CAA 2013b). Cognitive impairment in children is defined by WHO as a reduction in cognitive ability in school-age children that occurs while exposed to noise and persists afterwards, but it is not a health outcome that can be clinically diagnosed (WHO Europe 2011).

Noise affects central processing, language skills, reading, comprehension, memory and long-term attainment (Airports Commission 2013). Noise events may also lead to lost teaching time, an annoyance and stress response, impaired attention, and sleep disturbance (Basner et al. 2014; Stansfield and Clark 2015). It is not clear whether the overall dose of sound energy, the number of events, or the maximum noise level has the greatest effect on children's learning.

There is growing evidence that noise affects hyperactivity but the current evidence base suggests it does not have serious mental health impacts such as anxiety in children (Stansfeld and Clark 2015). There is also uncertainty about the long-term effects of exposure to aircraft noise on cognitive development of children, with the evidence suggesting that the deficit in learning disappears if the child is no longer exposed to aircraft noise. More longitudinal studies have been called for by ENNAH to develop knowledge of the long-term impact of aircraft noise on children's learning (ENNAH 2013).

Strength of evidence

Berry and Flindell describe the evidence of the impact of environmental noise on cognitive behaviour as SUFFICIENT (Berry and Flindell 2009). There is robust evidence from over 20 studies to demonstrate that aircraft noise exposure, at school or at home, has impacts on children's reading comprehension and memory skills (Stansfeld and Clark 2015). The evidence is currently stronger for aircraft noise than for road traffic noise, with the difference thought to be due in part to the variability and unpredictability associated with aircraft noise, but also to the number of studies that have been carried out to date (WHO Europe 2011).

There is robust evidence from over 20 studies to demonstrate that aircraft noise exposure, at school or at home, has impacts on children's reading comprehension and memory skills.

A key study that has greatly enhanced understanding of the impacts of aircraft noise on learning is the RANCH (Road traffic and Aircraft Noise and children's Cognition & Health) study. This study of 2844 9-10 year old children from 89 schools around London Heathrow, Amsterdam Schiphol, and Madrid Barajas airports found that aircraft noise was associated with poorer reading comprehension and recognition memory, after taking into account social background and road traffic noise (Stansfeld et al. 2005).

UK primary school children in the RANCH study were exposed to aircraft noise levels ranging from 34 dBA Leq (16 hour) to 68 dBA Leq (16 hour) and the study found a linear relationship between aircraft noise and both impaired reading comprehension and recognition memory. A 5 dBA increase in daytime exposure of aircraft noise corresponded with a two months delay in reading age amongst UK pupils, with 50 dBA acting as the onset threshold (Basner et al. 2014).

A 5 dBA increase in daytime exposure of aircraft noise corresponded with a two months delay in reading age amongst UK pupils.

The results were particularly significant considering the relationship was present even after taking account of socioeconomic and confounding factors, such as exposure to traffic noise (Clark 2015). Since exposure to noise was similar at both home and school for most children, it was unclear whether the effect on impaired reading comprehension was attributable to night-time or daytime noise. The RANCH study considered self-reported sleep quality but there was no evidence that night noise was having an impact that was additional to daytime noise

(Clark 2015).

The findings of the RANCH study were recently reinforced by the NORAH study around Frankfurt Airport, which found that a 10 dBA Leq increase in daytime aircraft noise was associated with a delay in learning of 1 month (NORAH 2015). Additionally, children exposed to more aircraft noise were found to be in worse general health than those exposed to less noise.

Long-term effects

A study by Hygge et al. (2002) on the relocation of Munich airport found that the cognitive deficit associated with high levels of aircraft noise disappeared two years after the airport's closure but that it developed for school children overflown by aircraft from the new airport (Hygge et al. 2002). This suggests that children no longer exposed to high levels of aircraft noise would be able to overcome the deficit.

A six year follow-up of the UK cohort in the RANCH study by Clark et al. (2013), looked at whether the noise levels the children were exposed to while in primary school (during the original RANCH study) had any long-term effect on the annoyance levels, reading comprehension and psychological health of the children. The study also looked at whether the noise levels now experienced by the children at secondary school had an effect on these factors, and likewise whether the cumulative effect of noise exposure at primary and secondary school had an effect. Clark et al. (2013) found that the children exposed to aircraft noise in primary school were significantly more annoyed by aircraft noise than other students at the same secondary school, suggesting a long-term annoyance response.

The Airports Commission identified that 466 schools around Heathrow were exposed to aircraft noise above WHO recommendations.

The Clark et al. (2013) study also found a negative association between reading comprehension and aircraft noise exposure at primary and secondary school, but evidence for the relationship was not strong enough to be statistically significant. The negative association was actually greater for cumulative and secondary school noise exposure than for exposure levels at primary school. The authors believed this suggested a long-term effect on reading comprehension from aircraft noise, but the size of the sample prevented any significant findings (Clark et al. 2013).

Scale of the problem

WHO recommends that noise in school outdoor playgrounds should not exceed 55 dBA Leq (16 hours). While there are no national assessments available, work for the Airports Commission identified that 466 schools around Heathrow were exposed to aircraft noise above 54 dBA Leq (16 hours), the closest contour to the WHO recommended level (Jacobs 2014). More than 240 schools were overflown more than 20 times in the day with a maximum noise exposure level of greater than 70 dBA (Jacobs 2014). The same report highlighted that 15 schools were exposed above the WHO level around Gatwick, and 9 schools were overflown more than 20 times in the day with a maximum noise exposure level of greater than 70 dBA. This indicates a serious problem for children learning around Heathrow. The issue of noise insulation is considered in the policy response section.

Evidence summary for memory and learning in children

Threshold: The RANCH study identified an onset threshold of 50 dBA Leq (16 hour) (WHO Europe 2011)

Exposure-response relationship: The RANCH study produced a linear dose response relationship between aircraft noise and both impaired reading comprehension and recognition memory, with a 5dB increase in exposure to aircraft noise corresponded with 2 month delay in reading age amongst UK pupils (Basner et al. 2014)

Strength of evidence: SUFFICIENT according to Berry and Flindell (2009)

Research needs: More longitudinal studies have been called for by ENNAH to develop knowledge of the long-term impact of aircraft noise on children's learning (ENNAH 2013).

1.6 MENTAL HEALTH AND THE BENEFITS OF QUIET AREAS

The theory

A concern for communities and campaigners is that the short-term impacts of sleep disturbance and annoyance may have long-term implications for an individual's mental health. There is some evidence linking aircraft noise with psychological symptoms, including anxiety and depression, and it has been suggested that certain groups are more vulnerable to noise, including people with pre-existing mental health issues, children and the elderly (Airports Commission 2013). For example, there is growing evidence that noise affects hyperactivity in children (Stansfeld and Clark 2015). There is currently a lot of uncertainty about the links between aircraft noise and long-term mental illnesses, such as anxiety and depression.

Benefits of quiet areas

There are clear benefits of having access to quiet areas on mental health and wellbeing, suggesting that noise could have detrimental effects if it reduces the availability of quiet areas. A recent Defra (2014a) report highlighted the value of quiet areas and the need to protect them. It identified benefits including improvements to creativity, problem solving, mental health, concentration and sleep and argued that quiet areas can result in savings in health care costs and increased productivity (Defra 2014a). WHO recommends that existing large quiet outdoor areas, such as parkland and conservation areas, should be preserved, and the number of noisy events compared to the background noise level kept to a minimum (WHO 1999a). This is reflected in the Environmental Noise Directive 2002, which refers to the need to preserve quiet areas in agglomerations. In the U.S., the impact of noise on quiet areas is an active topic of research, supported by the FAA's research roadmap (see for example Wolfe et al. 2014). Alternative noise metrics such as L90 which looks at the noise levels for 90% of the time could enable policy makers to make more accurate assessments of the impact of noise on quiet areas.

Alternative noise metrics which look at background noise levels could enable policy makers to make better assessments of the impact of noise on quiet areas.

Strength of the evidence

Based on current evidence, aircraft noise is associated with decreased quality of life but there is insufficient evidence to conclude it is causing psychological ill-health through annoyance (Clark 2015; Health Protection Agency 2010). However, this view has been challenged recently by the findings of the NORAH study in Germany which identified significant associations for aircraft noise and depression (NORAH 2015). The study produced a dose-response relationship for aircraft noise and depression, with an increased risk of depression of 8.9% per 10 dBA increase in noise. This relationship was found to be particularly strong for people who were psychologically sensitive.

The study produced a dose-response relationship for aircraft noise and depression, with an increased risk of depression of 8.9% per 10 dBA increase in noise.

There is evidence to suggest that protecting quiet areas does have health benefits and the next Defra IGCB(N) guidelines are likely to attempt to monetise these benefits.

Evidence summary for long-term mental health

Strength of evidence: INSUFFICIENT (Clark 2015). The evidence base is improving, though, with the NORAH study being able to identify a dose-response relationship between aircraft noise and depression.

Research needs: Establish whether there are long-term effects from annoyance and sleep disturbance on psychological ill health.

PART TWO: THE POLICY RESPONSE

2.1 THE IMPORTANCE OF HEALTH IN NOISE POLICY

2.1.1 WHO GUIDANCE

The WHO has been a key actor both in bringing together the evidence linking environmental noise and health and producing guidelines for protecting health. The 1999 Guidelines for Community Noise (referred to as 'environmental noise' in this report) drove the health implications of environmental noise to be taken seriously at a policy level. Produced by an expert panel, the guidelines evaluated the strength of evidence for different health effects and suggested guideline values for thresholds of exposure in specific dwellings and to avoid health effects.

The guidelines concluded that during the day, noise levels in outdoor living areas should not exceed 55 dBA Leq (16 hour) to protect the majority of the population from being 'seriously annoyed' and outdoor noise at night should not exceed 45 dBA Lnight and 60 dBA Lmax for individual night-time events to offer protection from sleep disturbance. WHO also set out separate guideline values for schools, hospitals and parklands and conservation areas and argued for the precautionary principle to be applied to protect public health while supporting evidence was developing.

The UK Government was the lead signatory to the WHO's Charter on Transport, Environment and Health in 1999. This made an explicit commitment to introduce targets that take into account recommendations from the WHO guidelines and keep night-time sound levels in residential areas within the WHO recommended night time values (WHO 1999b). This charter remains extant today though no policy plan has ever been developed at a national level to deliver it and the UK Government has increasingly distanced itself from achieving the 1999 Community Noise Guidelines.

In 2009, WHO published its night noise guidelines for Europe, based on the latest evidence base (WHO Europe 2009). These guidelines introduced a new guideline value for night noise of 40 dBA Lnight (lower than in the 1999 guidelines) on the basis of updated evidence, and in order to protect vulnerable groups (children, the elderly, and shift workers). WHO also set out an interim target of 55 dBA Lnight to help policy makers in moving towards long-term goals, and highlighted that there is a particular public health concern above this level.

New WHO guidelines are expected in 2016, informed by the evidence base discussed in part one of this report, and will provide policy makers with a new opportunity to introduce long-term noise targets. The rest of this section will look at the policy response to date based on the development of evidence and the availability of WHO guidelines.

WHO Guidelines summary

Daytime noise
Long term target: outdoor noise should not exceed 55 dBA Leq 16 hour

Nightime noise
Long term target: 40 dBA Lnight
Interim target: 55 dBA Lnight

2.1.2 THE POLICY RESPONSE TO HEALTH BASED GUIDELINES

EU policy

The development of WHO noise guidelines has had a direct impact on policy. WHO's 1999 Community Noise Guidelines led to the 2002 EU Environmental Noise Directive (2002/49/EC) (END), which introduced a common approach to "*avoid, prevent, and reduce the harmful effects of environmental noise*" (article 1). However, there is no explicit target in the END for noise to be reduced in line with the WHO recommendations.

The EU's 7th Environment Action Plan contained an objective for noise pollution to significantly decline by 2020 towards WHO recommendations but the the END as it stands contains no explicit health-based limit values

END requires publicly available noise exposure maps for major sources of road, rail and aircraft noise and larger urban areas and the adoption of action plans with a view to reducing noise where necessary and where exposure induces harmful effects. These maps and noise action plans are required to be updated every five years. In 2013, only 62% of major airports across the EU had produced noise action plans, but all 17 UK airports with more than 50,000 movements had produced action plans by 2014 (Defra 2014a; ENNAH 2013).

The mapping requirement has improved exposure estimates from different noise sources, including through the use of standardised methodology. This data provides an estimate of the size of the population exposed to noise above certain levels. The END requires maps to assess noise upwards from 55 dBA Lden. In the UK, the publicly available noise exposure maps date back to 2006 as the revised 2011 maps were not published. The next round of noise exposure mapping should be published in 2017, based on aircraft noise levels for 2016.

Annex II of END contains guidance on a common methodology for noise exposure monitoring, and the European Commission is required to establish methods for assessing the harmful effects of noise on populations by using dose-effect relations, through annex III. This annex is expected to be developed in 2016 based on the next WHO guidelines and the WHO Europe 2011 methodology, and is expected to provide a standardised methodology for assessing the health impacts of noise.

Europe's first noise assessment report did highlight that the EU's 7th Environment Action Plan ('Living Well, Within the Limits of our Planet') contained an objective for noise pollution to significantly decline by 2020 towards WHO recommendations (EEA 2014). The document noted that this would require, in particular, implementing an updated EU noise policy aligned with the latest scientific knowledge, and measures to reduce noise at source. However, the END as it stands contains no explicit health-based limit values , (in contrast, for example to the Ambient Air Quality Directive which addresses air pollution impacts), and neither does it prescribe what kind of measures should be included in noise action plans.

UK policy

UK policy also lacks an overarching goal to reduce noise towards WHO recommendations. The Noise Policy Statement for England (NPSE), published by Defra in 2010, has the aim of promoting "*good health and a good quality of life through the effective management of noise within the context of Government policy on sustainable development*" (Defra 2010a, p.3) and objectives to avoid significant adverse impacts on health, and improve noise and quality of life. While the policy is intended to ensure that noise is taken into account in decision-making, there is no requirement to reduce noise to health-based levels.

The Government's overall policy on aircraft noise continues to be to "limit and where possible reduce the number of people in the UK significantly affected by aircraft noise"

The Government's latest planning policy, the National Planning Policy Framework (NPPF), has a noise-specific aim, informed by the NPSE, to avoid significant adverse impacts on health and quality of life, and indicates that the health impacts of noise should be considerations in development decisions (DCLG 2012).

Aviation noise policy

The Government's aviation policy between 2003 and 2010, the White Paper on the Future of Air Transport (ATWP), stated that the Government would take account of WHO's guidelines and support research to obtain better evidence about the health impacts of aircraft noise (DfT 2003). It did not, however, say how the Government would take account of WHO guidelines.

The current aviation policy, the Aviation Policy Framework (APF), which replaced the ATWP, makes no direct reference to WHO guidelines. It does reference the NPPF and NPSE in relation to noise. The Government's overall policy on aircraft noise continues to be to "*limit and where possible reduce the number of people in the UK significantly affected by aircraft noise*" (DfT 2013a, page 11). This does not directly consider the health impacts discussed in part one of this report. For mitigating the impacts of noise, the Government's policy is based on striking a balance between "*the negative impacts of noise (on health, amenity (quality of life) and productivity) and the positive economic impacts of flights*" (page 55). This means that measures to mitigate noise should be "*proportionate to the extent of the noise problem and numbers of people affected*" (page 55).

In the APF, the Government decided to retain the use of the 57 dBA Leq noise contour as marking the onset of significant community annoyance, saying that "*there are still large uncertainties around the precise change in relationship between annoyance and the exposure to aircraft noise*" (page 58) and that the 57 dBA Leq contour would "*provide historic continuity*" (page 57). This is despite the Government's own research, the ANASE report, suggesting it is no longer appropriate, and the evidence in part one of this report indicating a need to update dose-response curves for annoyance. The DfT has commissioned a new attitudes survey which is expected to be published in 2016 so it will have an opportunity to update its annoyance policy based on the findings.

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The APF did recognise the need to consider alternative noise metrics for assessing the impact of noise on communities and recommended that average noise contours should not be the only measure for explaining the effects of aircraft noise. The Government's noise policy for certain issues, including night noise and flightpaths, is set out below.

Night noise policy

The Government demonstrates an awareness of the health implications of sleep disturbance, stating in the APF that "*costs on local communities are higher from aircraft noise during the night, particularly the health costs associated with sleep disturbance*" (DfT 2013a, p.62).

Under the Civil Aviation Act 1982, the Government has discretionary powers to manage noise at 'designated airports'. Currently, Heathrow, Gatwick and Stansted are designated for this purpose with decisions informed by the publication of annual noise exposure maps for these three airports, produced by the Civil Aviation Authority (CAA). Under these powers, the Government limits night-time aircraft noise using absolute limits on the number of flights and quota counts but the restrictions have not been significantly modified since 2006.

How important is health in the Government's noise policy?

When WHO published its 1999 community noise guidelines, and again when the 2009 guidelines were published, they provided guidance in reducing the health impacts of night noise based on expert evaluation of scientific evidence in Europe. The UK Government signed a Charter following the 1999 Community Noise Guidelines, saying that it would introduce targets that take into account the WHO recommendations. However, policy documents following the 2003 ATWP have distanced the Government from the WHO guidelines and particularly the commitment in the Charter to aim to meet them for night noise. Banatuala and Rao (2013) revealed that the draft APF had not been sent to the Department for Health for comment, despite the evidence in part one of this report indicating that aircraft noise is an issue for public health. Taken together, this suggests that protecting health is not a priority in current aviation policy, even if it acknowledges the health impacts of aircraft noise in certain cases, particularly for night noise.

The Government's overarching aircraft noise policy lacks any direct reference to health impacts, and provides no meaningful benchmark or target. The Government's retention of the 57 dBA Leq contour as its threshold for indicating the onset of significant annoyance is a good example of the Government's failure to update policy in line with the evidence.

The most recent review of these guidelines was launched in 2013, at roughly the same time as the APF was published. In the first consultation, the Department for Transport (DfT) published a review by the CAA of the latest literature (CAA 2013b), referred to in part one of this report, and a monetisation methodology proposal (CAA 2013a) referred to later. In relation to the CAA review, DfT's document stated that "*there is evidence to suggest that long term exposure to noise at night can result in adverse health effects*" (p.63) and that the review "*has shown that night time aircraft noise can have significant health effects on the local population and that several health impacts can be quantified and monetised*" (DfT 2013a p.74).

> ***While the Government's decision document acknowledged that there are adverse effects on sleep from night noise the Secretary of State concluded that the present restrictions would be maintained rather than increasing their stringency***

This suggested that the Government is aware of the importance of sleep disturbance for health, as highlighted in the evidence section. Many respondents to the Government's night noise consultation called for the precautionary principle to be applied and night flights banned (DfT 2014a).

However, while the Government's decision document acknowledged that there are adverse effects on sleep from night noise the Secretary of State concluded that in order to balance the economic benefits of night flights against the adverse impacts, it would maintain the present restrictions until 2017 rather than increase their stringency.

To what extent does the Government's current night noise policy approach consider health?

The environmental objective underpinning the current night noise restrictions at Heathrow, Gatwick and Stansted is to limit and where possible reduce the numbers of people significantly affected by noise (in line with the Government policy) by limiting the maximum number of permitted movements during the night and encouraging the use of quieter aircraft to reduce the likelihood of sleep disturbance.

Progress towards the goal is shown by monitoring the numbers of people exposed to night noise above 55 dBA Lnight. The approach to monitoring is justified with reference to the interim target set out in the WHO night noise guidelines. It does not, however, measure noise levels down to the 40 dBA Lnight level recommended in the 2009 guidelines as the noise level to protect health.

While the restriction is designed to limit sleep disturbance, the WHO and the evidence reviewed in part one, emphasise that monitoring this objective requires a metric that focuses on the maximum noise level. Indeed, Leipzig/Halle airport in Germany introduced noise policy that explicitly sets out to limit the number of additional awakenings induced by aircraft noise, and Zurich and Frankfurt also introduced the use of noise metrics that monitor night-time aircraft noise in terms of the total number of awakening reactions elicited (Hume et al. 2012).

While night noise policy is the part of aircraft noise policy that most explicitly considers health, no changes have been made to the restrictions at Heathrow, Gatwick and Stansted for 10 years. The evidence discussed in part one of the report highlights the health benefits of a night flight ban. For example, the findings of the NORAH study indicate that a partial night flights ban would reduce sleep disturbance during a ban period but would increase disturbance after the ban period (NORAH 2015). As discussed later, the health cost associated with sleep disturbance is one of the largest public health impacts associated with aircraft noise.

Why should airspace change policy take health into account?

Neither airspace change policy nor process explicitly considers the health implications of a flightpath change. There is a clear need for airspace change policy and process to be brought in line with the latest health evidence.

Recent trials of flightpaths around some of the UK's airports led to significant community opposition and a rise in the number of complaints. In some cases, flightpaths became more concentrated, leading to some people being subjected to significant increases in noise exposure and in the frequency with which they were overflown. In other cases, the flightpaths were moved affecting new communities. The level of opposition is likely to have been associated partly with the step change in noise exposure experienced, leading to an annoyance response not predicted by the established annoyance curves, the so-called 'change effect' response described in the NORAH study (2015). A similar effect occurred after the opening of a fourth runway at Frankfurt. However, current airspace change policy doesn't consider this likely effect.

There is a wider issue in relation to appropriate metrics that suggests a need to update how airspace decisions are taken. CAA's current process recommends the use of SEL noise contours to assess sleep disturbance. However, WHO and the evidence considered in part one of this report recommend use of Lmax noise estimates along with average night-time noise metrics. Proposed airspace changes should ideally be considered using a range of noise metrics including both average levels and single event metrics, and should take account of the latest evidence in relation to noise impacts at different times of the day and night.

The delay was also intended to create policy stability while the Airports Commission addressed the issue of short-term capacity at the London airports. Despite having commissioned the CAA to develop a methodology for monetising the health costs of sleep disturbance, the 'balance' referred to by the DfT is based on an Impact Assessment, which did not monetise the health costs.

Flightpath changes

Flightpaths are an important factor in how noise affects communities and recent flightpath trials have caused significant disturbance around the UK. The Government highlights its noise policy on airspace change in the APF, stating that consistent with its overall aircraft noise policy, the Government favours, in most cases, concentration of aircraft along the fewest possible number of flightpaths, avoiding densely populated areas. The APF does suggest a role for respite in some circumstances.

The CAA is responsible for the airspace change process and sets it out for permanent changes in CAP725 - *CAA Guidance on the Application of the Airspace Change Process* (CAA 2007). CAP725 requires an environmental assessment which looks at the noise impacts of a flightpath change, and an airspace change is only allowed to be made if there is a clear overall environmental benefit or where the need for safety allows for no practical alternative.

Airspace change proposals are required to produce Leq contour maps for daytime noise, including the Government's 57 Leq noise annoyance contour (as discussed), and to provide estimates of the numbers of households or of the population size within this contour. Also required are SEL noise contours which show the extent of noise energy generated from a single aircraft event. CAA suggested that this noise metric could be useful for assessing the likelihood of sleep disturbance. The number of schools and other noise sensitive buildings are not required to be set out in the airspace change process. The CAA is currently reviewing the CAP725 process, while Government is also expected to update its airspace policy in 2016.

Airport capacity

A decision to build a new runway in the South East could have major implications for the noise environment around Heathrow or Gatwick, which in turn could have implications for public health. The Government set up the Airports Commission in 2012. Under its terms of reference, the Commission was required to prepare documents so that a National Policy Statement on aviation could be produced after the Commission's final recommendations. The National Policy Statement would require an environmental statement under the Planning Act 2008 which would have to consider noise as an environmental impact.

A decision to build a new runway in the South East could have major implications for the noise environment around Heathrow or Gatwick, which in turn could have implications for public health.

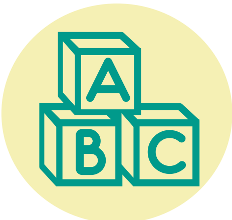
The Airports Commission published its final report in July 2015, which recommended that a third runway at Heathrow was the preferred option for expansion. The recommendations included a series of conditions, primarily focused on aircraft noise. A literature review on aircraft noise and health, carried out by Dr Charlotte Clark of Queen Mary University, was also published with the final report. Two of the recommended conditions for expansion were linked directly to the health impacts of aircraft noise:

1. A ban on flights from 11.30pm – 6am (a partial night flight ban)

2. A recommendation that Heathrow Airport should prioritise insulation of schools when honouring its commitment for £1 billion of compensation

While two of the noise conditions for expansion recommended by the Airports Commission were tied to health impacts, it is unclear to what extent the health impacts of airport expansion

What is the role of insulation in protecting children's health?



The Airports Commission's final report states that noise insulation could mitigate the health effects of noise, particularly in relation to children's educational performance (Airports Commission 2015a). The review by Clark (2015) for the Airports Commission recommended insulating the schools that would be subject to a step-change in noise exposure to high levels of noise and also that insulation of schools should not be limited to those worst affected. While few studies have examined the effectiveness of insulation in providing noise abatement, evidence suggests that a reduction in noise can eliminate cognitive deficit with respect to the indoor learning environment (Stansfeld and Clark 2015).

Current Government policy, outlined in the APF, expects airport operators to offer acoustic insulation to noise-sensitive buildings, such as schools and hospitals, exposed to levels of noise of 63 dBA Leq (16 hour) or more. This is, however, significantly above the onset threshold for impairing memory and learning in children indicated by the RANCH study of 50 dBA Leq.

In 2015 Heathrow Airport finished providing insulation for 42 community buildings (including schools and nursing homes) that were within the 63 dBA Leq noise contour in 2002, at a cost of £4.8 million (Heathrow Airport Limited 2015). Over 460 schools are exposed to aircraft noise from Heathrow Airport above 54 dBA Leq (Jacobs 2014) and the vast majority have not received any form of insulation from the airport. According to the Airports Commission, Heathrow expansion would lead to more schools being overflown than would be affected without expansion, with an additional 24 schools falling within the 54 dBA Leq (16 hour) noise contour in 2050 compared to the baseline (Clark 2015). A number of these schools would be newly overflown by a significant number of planes, with a maximum noise level above 70 dBA.

It is unclear what the cost would be of insulating all schools exposed to noise above 50 dBA Leq or how this might affect the case for runway expansion in the South East.

featured in the overall decision-making process in relation to a new runway. This is considered later in the report.

2.1.3 SECTION SUMMARY: POLICIES LAG BEHIND THE EVIDENCE AND GUIDELINES

In summary, as the evidence of health effects has accrued over the past 20 years, the guidance from the World Health Organisation has provided policy makers with goals that should be met to protect health. However, Government policies appear to be lagging behind. The EU has an ambitious long-term target of reducing noise levels towards the WHO guidelines but this ambition has not been translated into legislation or policy at the EU or national level. For aviation policy, it is increasingly apparent that aviation represents a public health risk on which Government needs to act. However, noise objectives for aviation continue to be to limit the impacts of noise rather than to reduce noise. The indicators used in policy to assess the effect of noise on communities are also out-of-date, particularly the continued use of the 57 dBA Leq (16 hour) noise contour as indicating the onset of community annoyance. DfT has commissioned a new attitudes survey which is expected to be published in 2016 and offers a fresh opportunity for updating its annoyance threshold based on the latest evidence.

The emphasis present in all aviation policy on balancing the economic benefits of aviation with environmental costs highlights an inherent tension in policy-making, as addressing the public health imperative as the WHO recommends could place a burden on the aviation industry. This is, AEF considers, a key reason why there is a lack of legislation to aim towards achieving the WHO guidelines. There is, however, significant progress being made in how applying a monetary value to the health effects of noise can help to inform policy decisions. The next section considers the benefits and limitations of this approach.

2.2 HOW DECISION MAKING CAN BE BETTER INFORMED BY HEALTH IMPACTS

2.2.1 GUIDANCE FOR ASSESSING HEALTH IMPACTS

In 2011, WHO Europe published its assessment of the impact on public health, known as 'Burden of Disease', across Western Europe due to environmental noise, and in 2012 provided accompanying technical guidance (WHO Europe 2011; WHO Europe 2012). This work was aimed at policy makers, and enabled them to assess the impact on the health of their citizens from a specific noise source. This process can then be useful for informing policy decisions.

The WHO approach combines noise exposure data with knowledge of how noise leads to a health impact (see part one), to calculate the effect on the health of a population of given noise levels in terms of both premature deaths and ill health. In the UK, noise exposure data is available for all major airports, as defined under END legislation, and the CAA also provides annual noise data for the three designated London airports – Heathrow, Gatwick and Stansted.

WHO assesses Burden of Disease by using Disability Adjusted Life Years (DALYs). This approach combines years of life lost due to premature death and equivalent years of "healthy" life lost by virtue of being in state of poor health or disability (WHO Europe 2011). In the UK, Quality Adjusted Life Years (QALYs) have tended to be used in the past, but they are more or less equivalent to DALYs. If a certain level of aircraft noise led to a health outcome it would reduce the number QALYs/DALYs due to the time spent with the health condition (the effect on the quality of life would vary depending on the condition), premature death or a combination of the two (Harding et al. 2013). This can then be assessed across a population based on noise exposure data.

For DALYs, a disability weighting of between 0 and 1 is applied for a given health outcome, indicating the severity of the health effect on a person's quality of life. WHO calculated disability weights for a large number of health impacts, including cardiovascular disease, annoyance, sleep disturbance, and impacts on learning in children. However, there is uncertainty about the disability weighting for some health impacts, particularly annoyance and sleep disturbance, relating to the uncertainty about the effect on overall health of these impacts. WHO therefore produces low, medium and high disability weights which, as discussed later, can have significant impacts on the assessment of the health burden (see 2.2.4). The high disability weighting for annoyance is 12 times larger than the low disability weighting (Sanchez et al. 2014). See below for how a DALY/QALY is calculated.

Methodology for calculating DALYs and QALYs

DALYs are calculated as follows:

YLL – years of life lost which is calculated by multiplying the number of deaths by the standard life expectancy at age
+
YLD – years of life in disability, which is calculated by multiplying the number of incident cases (I) by the disability weight (DW) and by the average duration of disability in years (L).

QALYs are calculated as follows:

QLL - Quality life years lost (years of life with disability x quality of life (combining morbidity and mortality)
+ Life expectancy lost.

How the WHO calculated 'Burden of Disease' from environmental noise

In its 2011 assessment of the Burden of Disease from environmental noise across Western Europe, WHO calculated the number of DALYs lost for many of the health impacts considered in part one of this report, using the best available dose-response relationships. For sleep disturbance and annoyance, this involved using the EU dose-response curves (see 1.3 and 1.4). For cardiovascular disease, WHO Europe focussed on hypertension, and on AMI as an outcome of heart disease (see 1.2). The report used evidence from Babisch (2006) for AMI, and from Babisch and van Kemp (2009) for aircraft noise and hypertension, although DALYs were calculated only for heart disease related AMI, as there was no disability weight associated with hypertension itself. In the UK, Harding et al. (2011) provided additional assistance on quantifying the link between environmental noise and hypertension and health effects. The work assisted with methodologies for assessing the cardiovascular impacts on populations from specific noise sources. Research by Harding et al. (2011), referred to in section 1.2, used the relationship for hypertension and noise set out by Babisch and van Kemp (2009) to assess the increased risk of AMI, stroke and dementia in a population. This work has then informed Defra's recommendations for monetising health effects from noise, discussed later.

WHO Europe highlighted that there was no generally accepted method for quantifying cognitive impairment in children as a disability weighting, but did assess the number of DALYs lost based on several studies including the RANCH study. Given the very low disability weighting attached to impaired learning, the assessed DALYs are likely to underestimate the societal impact of aircraft noise on cognitive impairment, WHO Europe argues.

WHO Europe calculated that the total annual burden of disease from environmental noise in Western Europe was 1-1.6 million DALYs, making it the second largest public health risk in Western Europe.

Using this methodology, WHO Europe calculated that the total annual burden of disease from environmental noise in Western Europe was 1-1.6 million DALYs . This calculation identified environmental noise as the second largest public health risk in Western Europe, and sleep disturbance and annoyance are main contributors to ill health. However, while cardiovascular disease is a small component of the health burden, it is directly associated with premature death. The impacts are set out in figure 7.

2.2.2 INFORMING POLICY DECISION MAKING: THE ROLE OF MONETISATION

In the UK context, policy interventions increasingly have to be justified in cost-benefit analyses to assess whether the net impact of an intervention would be positive or negative. This means that it is easier for policy makers to justify a decision based on evaluating impacts that can be quantified. There is therefore a clear incentive for developing robust methodologies to monetise health impacts. Being able to monetise noise impacts can also provide a common language for policy makers, guide design of policies for noise management, allow contextualisation compared to other impacts and justify intervention, for example to demonstrate that the costs of noise outweigh the costs of controlling noise (Defra 2014a; Sanchez et al.

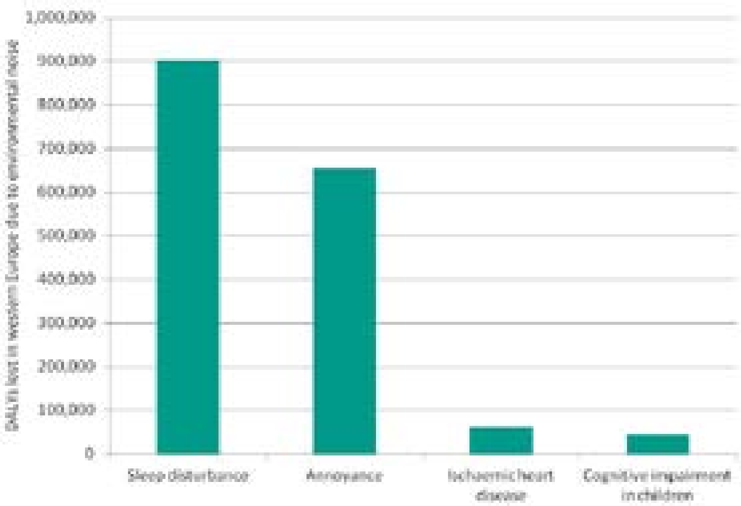


Figure 7: Size of the 'burden of disease' for specific health impacts from environmental noise
Source: Basner et al. 2014
903,000 DALYS are lost due to sleep disturbance; 654,000 DALYS due to annoyance; 61,000 DALYS due to ischaemic heart disease; and 45,000 DALYS due to cognitive impairment in children.

2014).

Health-based approaches to monetisation are increasingly the preferred option in UK policy, and corresponding methodologies have been established over the past five years. As discussed below, similar methodologies have been applied by Defra and CAA, and used by the Mayor of London, Sanchez et al. (2014), and the Airports Commission. The anticipated annex III of END is expected to introduce new guidance on common approaches to assessment of health effects, based on the WHO Burden of Disease approach. The following section looks at the new approach the Government now takes, how the Airports Commission monetised noise costs and AEF's view on the value of monetisation for informing policy. Monetisation of noise is not in itself a solution to the noise problem and limitations of this approach are discussed at the end of this section.

Health-based approaches to monetisation are increasingly the preferred option in UK policy, and corresponding methodologies have been established over the past five years.

2.2.3 MONETISING NOISE HEALTH IMPACTS IN THE UK: THE GOVERNMENT'S RECOMMENDED APPROACH

The Government's recommended approach for assessing the costs and benefits of proposed transport schemes is the Department for Transport's WebTAG methodology (Web-based Transport Analysis Guidance), which aims to capture both the direct economic benefits of a scheme and its environmental and infrastructure costs. Up until December 2015, the WebTAG methodology for assessing noise looked only at annoyance with the monetary value derived from a 2004 study which estimated people's willingness to pay for peace and quiet based on house price values (DfT 2014b). The methodology has been criticised for containing monetised annoyance values only for road and rail noise and not directly considering health (see London Borough of Hounslow, Mayor of London and Stop Stansted Expansion 2013). It also didn't consider night noise specific costs (CAA 2013).

In December 2015, the WebTAG methodology was updated based on the work of the Interdepartmental Group on Cost Benefits (Noise) (IGCB(N)), which is a Defra-organised group incorporating a range of Government departments with the remit to develop and disseminate best practice in economic approaches to assessing the impacts of changes in the noise environment. In 2008, IGCB(N) developed an 'impact pathway' (see figures 1 and 2) approach that draws on the major progress in noise and health literature and involves assessing noise exposure from specific sources, quantifying the health outcomes, and then monetising these impacts (Defra 2008). This approach is very similar to the WHO Burden of Disease methodology. The approach was supported in an expert economic evaluation by Professor Graham Loomes from the University of East Anglia, who said that it would appear to be entirely feasible and "*highly desirable*" (Defra 2010b).

IGCB(N)'s latest recommendations from 2014 allow for separate appraisal of aviation noise and proposes a DALY-based appraisal methodology for annoyance, sleep disturbance, and three health outcomes from hypertension – AMI, stroke and dementia. The latest report notes that the impacts of noise on sleep disturbance should be monetised and reflected in policy option appraisals, with any uncertainties noted (as highlighted in the evidence section). This was also the approach advocated by the CAA when it produced a monetisation methodology as part of DfT's 2013 review of night noise regulations (CAA 2013a). Defra advocated use of an onset threshold of 45 dBA for assessing annoyance and sleep disturbance due to the unreliability of noise exposure data below this level. The methodology values a DALY at £60,000 based on Department for Health values.

For cardiovascular impacts, it was the first time that monetisation had included dementia and stroke as outcomes and applied the Harding et al. (2011) methodology discussed earlier, which IGCB(N) originally commissioned. For assessing heart attack, Defra maintained the approach it developed in its 2010 report, which involved using the dose-response relationships developed by Babisch (2006) as the best available evidence for appraisal purposes, despite uncertainties. CAA also recommended the use of the Babisch (2006) approach but substituting daytime values with night-time values in order to account properly for night noise (CAA 2013a).

Defra's work led to an update of the Department for Transport's WebTAG methodology which came into effect in December 2015 (DfT 2015a). This now takes up the impact pathway approach and, importantly, there are now specific figures for aviation noise as well as road and rail noise. According to the updated WebTAG methodology, the most significant development is the inclusion of methods for appraising sleep disturbance for the night period 11pm – 7am (DfT 2015a).

As discussed earlier, sleep disturbance and annoyance are the most widespread health impacts (see figure 7). The new WebTAG methodology also provides details about assessing the distributional impacts of noise, particularly the inclusion of older people as a group of interest, given the evidence that health impacts, especially AMI and stress and dementia, are particularly relevant to older people (DfT 2015b).

Using the Government's methodology to assess national aircraft noise costs

The Defra IGCB(N) 2014 work led to the development of a tool to model transport noise costs, permitting the assessment of marginal costs associated with aircraft noise at different levels as well as total noise costs.

AEF has used the figures provided in the WebTAG methodology to assess the national costs of aircraft noise on health. The noise exposure data is based on information produced for and published by the Airports Commission which provided figures for the populations living within noise contours for daytime, night, and weighted 24 hour noise (see Jacobs 2014). The full working out and any assumptions made in AEF's assessment can be found in the Annex. The strengths and limitations of monetisation as an approach are considered at the end of this part of the report.

AEF conservatively estimates that aircraft noise imposes a public health cost in the UK of £540 million each year.

It is likely that this value significantly underestimates the cost of aircraft noise on health each year. The costs are broken down below for each impact:

Sleep disturbance

The Defra / WebTAG methodology applies the WHO Europe (2011) burden of disease methodology for sleep disturbance based on the dose-response relationship set out by Miedema, using an onset threshold of >45 dBA Lnight. The key uncertainty is the variation in disability weighting between high, medium and low reflecting uncertainty in the impact on health.

Nationwide annual cost of aircraft noise related sleep disturbance: £275 million

Annoyance

The WHO Europe (2011) burden of disease methodology is again applied based on the Miedema dose-response relationship using an onset threshold >45 dBA LDEN. The key uncertainty is the variation in disability weighting between high, medium and low reflecting uncertainty in the impact on health, and the evidence suggesting the dose-response curve is likely to underestimate annoyance response from aircraft noise.

Nationwide annual cost of aircraft noise related annoyance: £198 million

Heart attack

The Babisch (2006) dose response curve is used to directly assess increased risk of heart attack based on daytime noise (Leq, 16 hour). The key limitations of this methodology are that it is not an aviation specific dose-response relationship and assesses the risk based on daytime noise rather than 24 hour noise.

Nationwide annual cost of aircraft noise related heart attack: £7.3 million

Hypertensive stroke

The Harding et al. 2011 methodology is used to assess the increased risk of hypertensive stroke based on Babisch and van Kemp 2009 dose-response curve for aircraft noise and hypertension of 1.13 per 10 dBA LDEN increase in aircraft noise, with an onset threshold of 55 dBA Lden. The key limitation is that it doesn't directly estimate increased stroke risk.

Nationwide annual cost of aircraft noise related hypertensive stroke: £23.9 million

Hypertensive dementia

The Harding et al. 2011 methodology is used to assess the increased risk of hypertensive dementia based on Babisch and van Kemp 2009 dose-response curve for aircraft noise and hypertension of 1.13 per 10 dBA LDEN increase in aircraft noise, with an onset threshold of 55 dBA LDEN. The key limitation is that it doesn't directly estimate increased dementia risk.

Nationwide annual cost of aircraft noise related hypertensive dementia: £36 million

Total nationwide annual cost of aircraft noise on health: £540 million

2.2.4 HOW THE AIRPORTS COMMISSION USED MONETISED HEALTH IMPACTS IN ITS RUNWAY RECOMMENDATION

The Airports Commission commissioned the CAA's Environmental Research and Consultancy Department (ERCD) to assess the health impacts of aircraft noise based on the CAA and Defra's IGCB(N) recommended methodology. These results were presented in an annex of the final report. Cardiovascular impacts were monetised using 24 hour unweighted noise exposure data, annoyance was monetised for daytime exposure and sleep disturbance was monetised for night time exposure. Based on the uncertainties discussed in relation to the appropriate disability weighting (particularly sleep disturbance and annoyance) the Commission produced low, medium and high cost assessments. The Commission also carried out sensitivity analyses for the onset of annoyance and sleep disturbance from 45dB to 48dB, as suggested by CAA where 48 dBA Lnight is derived from from planning guidance, PPG 24 (DCLG 2006) and 45 dBA Lnight from WHO. The Airports Commission's analysis used a DALY figure of £68,851.

The Airports Commission used the calculated noise health costs, summed over 60 years, to inform its cost-benefit analysis, which

Total costs over 60 years (£ billions)	Low	Medium	High
HAL - N	2.23	3.73	15.5
Sensitivity (use of 48 dBA threshold)	1.76	2.89	13.64

Table 1: Total health costs from aircraft noise over 60 years under a specific flightpath scenario (to minimise newly affected) for a third runway at Heathrow compared to the two runway baseline, with low, medium and high estimates based on disability weights, and sensitivity using a different onset threshold. Source: Environmental Research and Consultancy Department 2015

Minimise New	2030			2040			2050		
	Low	Medium	High	Low	Medium	High	Low	Medium	High
Annoyance	25.2	50.5	302.8	35.8	71.7	430.2	40.9	81.9	491.1
Sleep disturbance	23	40.2	57.4	26.5	46.4	66.3	10	17.6	25.1
AMI	9.8	9.8	9.8	18.2	18.2	18.2	18.5	18.5	18.5
HT Stroke	0.7	0.7	0.7	1.3	1.3	1.3	1.3	1.3	1.3
HT Dementia	1.1	1.1	1.1	1.9	1.9	1.9	2	2	2

Table 2: Airports Commission monetised noise costs of a third runway compared to the do minimum under a certain flightpath scenario for specific assessment years. Costs are stated in £millions/assessment year. Source: adapted from Environmental Research and Consultancy Department 2015

It is clear, as highlighted by the WHO Europe (2011) Burden of Disease work and AEF's national noise calculations that annoyance and sleep disturbance costs are by far the greatest noise health costs.

was presented in the final report (table 7.1, Airports Commission 2015a). The 60-year costs for a Heathrow third runway under a specific flightpath scenario are presented in table 1. A high disability weighting applied to annoyance and sleep disturbance (the high estimates in Table 1) results in total costs which are close to seven times greater than the medium figure, highlighting the uncertainty in the WHO disability weighting. Table 1 also highlights how assuming a different onset threshold for annoyance and sleep disturbance affects the assessed monetised costs.

Table 2 highlights the calculated noise costs for individual impacts of a three runway Heathrow compared to a two runway Heathrow in specific assessment years. It is clear, as highlighted by the WHO Europe (2011) Burden of Disease work and AEF's national noise calculations that annoyance and sleep disturbance costs are by far the greatest noise health costs, particularly when a high disability weighting is applied. The cardiovascular-associated impacts account for a smaller portion of the health impact but do relate to increased risk of premature death.

It is not possible to assess exactly how many AMI related premature deaths would arise each year with a Heathrow third runway.

AMI / heart attack

Table 2 demonstrates that increased risk of heart attack would have the highest cost of the cardiovascular impacts assessed. For the assessment year of 2040, the £18.2 million per year AMI cost corresponds with 264 AMI related DALYs lost that year. While the risk of death from an acute heart attack in the UK is 72% (Sanchez et al. 2014), it is not possible to assess exactly how many AMI related premature deaths would arise each year with a Heathrow third runway from the DALY value. The need to present actual health impacts is discussed in 2.2.5. AEF's AMI national calculation is lower than the Airports Commission's AMI assessment for a third runway at Heathrow, suggesting a possible under-calculation in AEF's assessment using the WebTAG methodology. It should be noted that uncertainties exist for the Babisch 2006 curve used, particularly since it is not specific to aircraft noise.

Hypertensive stroke and dementia

The costs associated with increased risk of hypertensive stroke and dementia are relatively low compared to the other health impacts. There is a range of approaches for estimating the dose-response relationship and the assessed costs will vary depending on the approach used. For example, the Harding et al. (2011) paper, which informed the methodology used by the Airports Commission, was based on the Babisch and van Kemp (2009) dose response relationship for hypertension and aircraft noise. However, in an updated paper, Harding et al. (2013) used a general environmental noise dose-response relationship put forward by van Kempen & Babisch (2012), which was based on the Leq

(16 hour) noise metric rather than rather than LDEN (24 hour). This would affect the size of the population identified as being affected; over one million people in the UK are exposed to aircraft noise above 55 dBA LDEN while 855,000 people are exposed to aircraft noise above 54 dBA Leq (16 hours). AEF calculated combined annual stroke and dementia costs from aircraft noise in the UK in the region of £59.9 million.

Annoyance

The annoyance costs vary significantly depending on the use of a high, medium or low disability weighting, with costs in 2040 varying from £35.8 million to £430.2 million per year. This significant variability led Sanchez et al. (2014) to argue that it may be impossible to produce accurate monetary values of health costs and that monetised figures should therefore be considered only indicative to understand trends. Sanchez et al. (2014) estimated annual annoyance costs from Heathrow, Gatwick and Stansted of £154m in 2006 and 2011; AEF's national aircraft noise annoyance assessment is £198 million.

Sleep disturbance

Sleep disturbance costs in the Airports Commission's assessment are the second highest after annoyance, but WHO Europe assesses sleep disturbance as having the greatest impact on their burden of disease assessment, as does the AEF assessment which assessed national sleep disturbance costs from aircraft noise at £275 million per year. The Commission also assessed the effects of a partial and full night flights ban on sleep disturbance costs, which can be found in table 3. The Commission calculated a saving of up to £7.5 billion over 60 years arising from a full night flights ban and £1.84 billion from a partial night flights ban compared to a two runway Heathrow operating with night flights. The table also features estimates of the population size affected by sleep disturbance, which demonstrates the extent of the population at risk of sleep disturbance. The estimated benefits in terms of reduced sleep disturbance are much greater for the full night flights ban than the partial night flights ban. This is consistent with the evidence discussed in section 1.3 as Clark (2015) highlighted the importance of noise in the shoulder periods (early mornings and late evenings) for vulnerable populations. The NORAH study indicated that a partial night flights ban would reduce sleep disturbance during the ban period but could potentially increase disturbance during the early morning (NORAH 2015).

The estimated benefits in terms of reduced sleep disturbance are much greater for the full night flights ban than the partial night flights ban.

In 2011, CE Delft monetised night noise health costs at Heathrow to estimate the benefit of a night flights ban, as part of a social cost benefit analysis. The study found that savings in relation to improved health and wellbeing would offset the economics costs of a ban by "a wide margin". CE Delft (2011) based their assessment of night noise on annoyance impacts, whereas the Airports Commission directly measured sleep disturbance but the conclusion that night noise has significant health costs is clear from both analyses.

2.2.5 SECTION CONCLUSION: HOW POLICIES CAN BE BETTER INFORMED BY EVIDENCE OF HEALTH IMPACTS

The work by Defra's IGCB(N) demonstrates how much the evidence and methodologies for monetising health impacts have changed in recent years. The 2010 Defra IGCB(N) report recommended that the evidence in relation to the monetary valuation of annoyance, mental health, hypertension, sleep disturbance, and cognitive development was not sufficiently robust to be used for policy appraisal (Defra 2010b). In its latest report from 2014, however, Defra recommended a monetisation methodology for annoyance, sleep disturbance, and three health outcomes from hypertension – AMI, stroke and dementia.

Monetisation of the health impacts of aircraft noise is, AEF considers, a useful input in the context of cost-benefit analysis and that is how the WebTAG methodology is intended to be used. AEF applied the updated DfT WebTAG methodology to assess annual national aircraft noise costs on health, producing an annual national health cost of £540 million. However, the example of the Airports Commission's approach demonstrates some of the limitations of solely using a monetisation approach for assessing the health impacts of aircraft noise, outlined below.

Scenario	Metric: Lnight 8hr	2030	2040	2050
LHR-NWR-T	Population exposed to aircraft noise at night above 45 dBA Lnight	617,100	712,700	698,700
	Monetised High Sleep Disturbance (HSD) (relative to two runway Heathrow) (£billion Net Present Value over 60 years)	£-0.42		
LHR-NWR-T no core-night flights	Population exposed to aircraft noise at night above 45 dBA Lnight	477,200	604,400	561,100
	Monetised High Sleep Disturbance (HSD) (relative to two runway Heathrow) (£billion Net Present Value over 60 years)	£-1.84		
LHR-NWR-T no night flights	Population exposed to aircraft noise at night above 45 dBA Lnight	0	0	0
	Monetised High Sleep Disturbance (HSD) (relative to two runway Heathrow) (£billion Net Present Value over 60 years)	£-7.5		

Table 3: Monetised benefits and population size affected for various night flights ban proposals under a certain flightpath scenario (to minimise total numbers affected (LHR-NWR-T). Costs given in £billions over 60 years. Source: adapted from Environmental Research and Consultancy Department 2015

AEF supports use of the precautionary principle and considers that the best available dose-response relationships should be used to inform cost-benefit analyses.

First, wide variations exist between cost estimates. This is partly related to fact that the science underlying the health effects is still emerging, particularly in relation to establishing correct dose-response relationships (Sanchez et al. 2014). There is a risk that the lack of a conclusive dose-response relationship for certain health impacts may mean that they may be excluded from cost-benefit analyses. AEF supports use of the precautionary principle and considers that the best available dose-response relationships should be used to inform cost-benefit analyses even if they are incomplete (and so may not fully reflect the health damage).

Second, monetisation is no substitute for the setting of appropriate targets to protect the public from the health impacts of noise. In its final report, the Airports Commission's health assessment for aircraft noise was presented as a monetary value rather than in terms of premature deaths or the broader health burden. The Airports Commission's final sustainability appraisal noted that the data used to monetise health impacts could also be translated into specific health indicators (such as increases in hospital visits) (Airports Commission 2015b). However, the Commission chose not to do this on the basis that the assessments relied on indicative flightpath assumptions, and that alternative assumptions could have had a significant impact on the findings. The Commission did, however, say that when clearer information is available, a full Health Impact Assessment should be undertaken, including consideration of the distribution of impacts, such as on vulnerable populations (Airports Commission 2015b).

Monetisation is no substitute for the setting of appropriate targets to protect the public from the health impacts of noise.

Third, there is no guarantee that the results of the cost benefit analysis will be used appropriately. In the Airports Commission's analysis, noise costs have a significant bearing on the overall assessment of the runway schemes considered, particularly at Heathrow where the anticipated benefit of the scheme overall over 60 years was found to be as low as £1.4 billion in a scenario where climate constraints were factored in (Aviation Environment Federation

policy makers would be in a better position to make decisions if the likely health impact is presented as well.

2015). However, the results of this analysis are rarely quoted, with the Commission preferring to use a figure of £147 billion benefit derived from analysis by consultants which did not reflect environmental costs.

Our view is that monetisation of the health impacts of noise can provide only indicative figures of the likely impact and policy makers would be in a better position to make decisions if the likely health impact is presented as well. This could be achieved through a full health impact assessment, which should assess impacts across different groups, including children, and accounting for the combined impact of different pollutants. Carrying out a full health impact assessment would produce a set of evidence-based practical recommendations that would inform decision-makers, and communities, on how best they can promote and protect the health and wellbeing of local communities (Department for Health 2010).

Policy decisions should be driven by the public health imperative outlined in the WHO guidelines and evidence section of this report to reduce noise to levels that are safe for public health.

More broadly, policy decisions should be driven by the public health imperative outlined in the WHO guidelines and evidence section of this report to reduce noise to levels that are safe for public health. Monetisation of health impacts can play a role in informing policy decisions but should only do so alongside a requirement to reduce noise levels to safe levels over the long term.

CONCLUSIONS AND RECOMMENDATIONS

Aircraft noise is a pervasive public health problem in the UK. Over one million people's health could be affected by aircraft noise, with an annual cost calculated by AEF of £540 million. This paper has sought to synthesise the latest evidence on aircraft noise and health, highlight the current state of government policies for considering noise and health in the context of WHO guidelines, and examine how policy makers can assess the public health impact from noise and use the information to inform policies and decision making.

Key recommendation: Government should commit to developing specific long-term targets focussed on protecting the public from the health impacts associated with aircraft noise.

The evidence

Part one examined the latest evidence supporting the link between aircraft noise and health, highlighting that huge progress has been made over the past decade. Reviews by WHO and others have concluded that there is sufficient evidence to demonstrate that noise leads to cardiovascular impacts, sleep disturbance, annoyance, and impairment to the cognitive development in children. There is also emerging evidence suggesting links between long-term exposure to noise and mental health impacts.

Some questions remain, however, about the exact dose-response relationships for aviation noise specifically, which would further improve understanding of the impacts on public health of aircraft noise. The Department for Transport, Defra, and CAA should ensure that they are informed by the latest scientific evidence. The UK Government should also, through regular attitudes surveys, continue to monitor changes in annoyance responses to aircraft noise. DfT commissioned an attitudes survey by Ipsos Mori and the findings are expected to be published in 2016.

The Guidelines

Successive WHO guidelines on community (1999) and night noise (2009) have informed EU noise policy, which has led to the requirement in the UK for publicly available noise exposure data and noise action plans, updated every five years. There are, however, no UK or EU targets to reduce noise in line with health-based evidence, despite recommendations from the WHO. In 2016, WHO Europe is expected to publish a new set of guidelines which will consolidate the latest evidence to produce new guidance for policy makers, including dose response curves that are specific to different transport sources. This will provide policy makers with the ability to assess the public health impact of aircraft noise and set out how the impact will be reduced.

Supplementary Recommendation 1: The Government should draw on all available evidence including the upcoming WHO guidelines, the upcoming DfT noise attitudes survey and any other recent research (including the research summarised in this report), in setting its long-term objectives for aircraft noise.

Informing policy

The existing evidence and WHO guidelines highlight the need for policies to take full account of health impacts. Certain policies have not shifted despite the availability of new evidence. A key recommendation of this report is for the Government to commit to reviewing and updating all aviation noise policy to reflect the advances that have been made in terms of the evidence of health impacts of noise. An aviation national policy statement is expected to be produced following the work of the Airports Commission, which could present an upcoming opportunity for the Government to update its aircraft noise policy.

The evidence is also increasingly useful for specific policy scenarios. For example, the response to a sudden increase in aircraft noise exposure from a new flightpath is expected to be much more severe, and above the established dose-response curve. This has implications for airspace change policy, which is expected to be updated this year along with the CAA's process for flightpath changes.

Supplementary Recommendation 2: the Government should review all existing policies to ensure they take full account of the health impacts from aircraft noise and that any changes are permitted only if they help to deliver the long-term noise goals.

Future aviation policy decisions for the Government

The Government is expected to make several major aviation policy decisions which could have profound implications for public health. AEF believes that these decisions should be fully assessed in terms of their impact on public health and whether they will help to reduce the health burden from aircraft noise. Any cost-benefit analysis should also be informed by monetised aircraft noise health impacts using the best available dose-response relationships. While uncertainties exist in relation to our understanding of some of the health outcomes, it is important that the precautionary principle is applied. The anticipated updates to the END annex are expected to recommend a standardised methodology for monetising noise health impacts across Europe.

1) A new runway

Firstly, the Government has yet to make a final decision on a new runway, which could have significant implications for local public health as a result of increases in aircraft noise and traffic noise, and a reduction in local air quality. The Airports Commission assessed that a third Heathrow runway would cost £3.7 billion in health impacts from aircraft noise. This cost did inform a cost-benefit analysis carried out by the Airports Commission. However, there is no evidence that a third runway would reduce noise towards levels that are safe for health. The Government needs to clearly demonstrate that it has a plan to ensure that a new runway would be compatible with health-based noise targets before proceeding. In addition, a full health impact assessment should be carried out for the runway assessment, to make it clear where the health burden will be, with a particular focus on vulnerable groups, including children and the elderly.

2) New night flights regulations

The night flights regime at Heathrow, Gatwick and Stansted will need to be decided on for the period beyond 2017. The Government committed in its last decision document to subjecting the guidelines to a full appraisal using the latest evidence on effects. This will be consulted on in 2016. The next regulations for night flights at the designated airports should act on the growing body of evidence identifying that the long-term health implications of night noise are particularly severe, and aim to reduce night noise as soon as possible.

3) Airspace changes as part of the future airspace strategy

It should be a requirement that the health impacts of any flightpath change proposals are assessed in light of the goals referred to in our overall recommendation, monetised and a decision made that is based on whether or not the aim of the flightpath change is to reduce noise towards health based levels. Any future flightpath decisions should directly consider health implications including where the health burden will be, with a particular focus on vulnerable groups.

Supplementary Recommendation 3: Future aviation policy decisions should assess the impact from aircraft noise on health, including undertaking health impact assessments where appropriate, and should ensure that health impacts are monetised to inform cost-benefit analyses.

Supplementary Recommendation 4: The Government should use its five yearly revisions of noise action plans and noise exposure maps to assess progress towards achieving its health-based noise targets for aviation.

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ANNEX: CALCULATION OF NATIONAL MONETISED AIRCRAFT NOISE RELATED HEALTH COSTS USING WEBTAG METHODOLOGY

The update to the WebTAG methodology recommends following a process set out in DfT (2015a), and the use of the IGCB(N) methodology and its associated modelling tool, Transport Noise Marginal Values Mode, to monetise noise related health costs.

The noise exposure data and estimates of the affected population are obtained from information produced for and published by the Airports Commission, which provided figures for the population living within noise contours for daytime, night, and weighted 24 hour noise around the UK's major airports as well as a total figure (see Jacobs 2014). See table A1 below.

Table A1 aircraft noise exposure in the UK. Source: Jacobs 2014

	Noise contour	Cumulative total number of people exposed	Contour band	Numbers of people living within contour bands
Day	>54 dB LAeq,16h	855,050	54-57 dB LAeq,16h	491,600
	>57 dB LAeq,16h	363,450	57-60 dB LAeq,16h	211,350
	>60 dB LAeq,16h	152,100	60-63 dB LAeq,16h	96,850
	>63 dB LAeq,16h	55,250	63-66 dB LAeq,16h	39,400
	>66 dB LAeq,16h	15,850	66-69 dB LAeq,16h	12,400
	>69 dB LAeq,16h	3,450	69-72 dB LAeq,16h	3,250
	>72 dB LAeq,16h	200	>72 dB LAeq,16h	200
Night	>48 dB LAeq,8h	578,950	48-51 dB LAeq,8h	314,350
	>51 dB LAeq,8h	264,600	51-54 dB LAeq,8h	137,650
	>54 dB LAeq,8h	126,950	54-57 dB LAeq,8h	73,150
	>57 dB LAeq,8h	53,800	57-60 dB LAeq,8h	35,500
	>60 dB LAeq,8h	18,300	60-63 dB LAeq,8h	13,450
	>63 dB LAeq,8h	4,850	63-66 dB LAeq,8h	3,250
	>66 dB LAeq,8h	1,600	66-69 dB LAeq,8h	1,550
	>69 dB LAeq,8h	50	69-72 dB LAeq,8h	0
	>72 dB LAeq,8h	50	>72 dB LAeq,8h	50
24-hour	>55 dB Lden	1,006,000	55-60 dB Lden	757,400
	>60 dB Lden	248,600	60-65 dB Lden	188,600
	>65 dB Lden	60,000	65-70 dB Lden	52,800
	>70 dB Lden	7,200	70-75 dB Lden	7,100
	>75 dB Lden	100	>75 dB Lden	100

The Defra noise modelling tool provides marginal (per 1 dB change in noise exposure) and total (cumulative marginal costs) monetary values for each impact pathway (sleep disturbance, annoyance, AMI, stroke and dementia) based on the dose-response relationships outlined in the report. However, total monetary values are only provided on a per household basis. AEF calculated total per person costs from cumulative marginal per person costs. Given the population exposure data is for a noise range (i.e. between 54 and 57 dBA Leq) this report has used the noise cost per person value provided in the Defra modelling tool for the mid-point in that range (i.e. 55.5 dBA Leq for the range 54 to 57 dBA Leq). For the top most contour band, such as above >72 dBA Leq,16h in the case of daytime noise, the lowest noise cost per person value is used (i.e. 72 dBA Leq).

This report, the Defra noise modelling tool and the WebTAG guidance notes the uncertainties in the monetised costs for different health impacts and the WebTAG guidance recommends producing a range of figures. This report only quotes the mid-range figures provided in the Defra noise modelling tool. While the noise modelling tool does state that it is intended to calculate marginal and total costs, its main use is for assessing the impact of a policy decision rather than the total effect of aircraft noise as has been used in this example.

Tables A2-A6 below outline the national noise costs for each of the impacts, along with any assumptions made by the author.

Table A2: Sleep disturbance
Assumptions and notes: The total cost per person is obtained from the transport noise modelling tool. Calculated total cost to a person at a mid-point dBA using cumulative values. Uses the mid disability weighting from WHO.

	Contour band	Numbers of people within contour band	Total cost per person for mid value in decibel band	Estimated cost
Lnight	48-51 dB LAeq,8h	314,350	£378.06	£118,844,104.05
	51-54 dB LAeq,8h	137,650	£487.29	£67,075,105.10
	54-57 dB LAeq,8h	73,150	£607.72	£44,454,399.07
	57-60 dB LAeq,8h	35,500	£773.27	£27,450,950.10
	60-63 dB LAeq,8h	13,450	£897.43	£12,070,421.66
	63-66 dB LAeq,8h	3,250	£1,021.59	£3,320,174.13
	66-69 dB LAeq,8h	1,550	£1,187.14	£1,840,071.03
	69-72 dB LAeq,8h	0	£1,228.53	£0.00
	>72 dB LAeq,8h	50	£1,228.53	£61,426.51
			Total cost	£275,116,651.66

Table A3: Annoyance
Assumptions and notes: Uses Lden and a mid-disability weighting

	Contour band	Numbers of people within contour band	Total Cost per person for mid value in decibel band	Estimated cost
24-hour	55-60 dB Lden	757,400	£157.90	£119,594,363.03
	60-65 dB Lden	188,600	£279.41	£52,696,516.75
	65-70 dB Lden	52,800	£402.67	£21,260,983.11
	70-75 dB Lden	7100	£575.75	£4,087,831.17
	>75 dB Lden	100	£638.60	£63,859.75
			Total cost	£197,703,553.82

Table A4: Direct AMI (heart attack)
Assumptions and notes: The IGCB(N) assessment uses Lday (12 hour) but not available for aircraft noise in the Airports Commission's assessment so have used 16 hour, following the conversion outlined in the noise modelling tool and the WebTAG update document (see DfT 2015a)

	Contour band	Numbers of people within contour band	Total cost per person for mid value in decibel band	Estimated cost
Day 16 hour	54-57 dB LAeq,16h	491,600	£1.33	£651,527.92
	57-60 dB LAeq,16h	211,350	£8.43	£1,781,608.33
	60-63 dB LAeq,16h	96,850	£21.54	£2,086,225.67
	63-66 dB LAeq,16h	39,400	£41.20	£1,623,323.15
	66-69 dB LAeq,16h	12400	£67.95	£842,616.50
	69-72 dB LAeq,16h	3250	£102.34	£332,600.81
	>72 dB LAeq,16h	200	£129.77	£25,954.29
			Total Cost	£7,343,856.67

Table A5: Hypertensive Stroke
Assumptions and notes: Uses Lden. There are concerns about the value of this tool for calculating total costs rather than additional costs from a change in noise exposure. See DfT 2015a and Defra 2014a for limitations.

	Contour band	Numbers of people within contour band	Total Cost per person for mid value in decibel band	Estimated cost
24-hour	55-60 dB Lden	757,400	£20.08	£15,209,260.58
	60-65 dB Lden	188,600	£31.62	£5,964,242.95
	65-70 dB Lden	52,800	£43.45	£2,294,309.74
	70-75 dB Lden	7100	£55.58	£394,590.81
	>75 dB Lden	100	£60.51	£6,050.98
			Total cost	£23,868,455.06

Table A6: Hypertensive Dementia
Assumptions and notes: Uses Lden. There are concerns about the value of this tool for calculating total costs rather than additional costs from a change in noise exposure. See DfT 2015a and Defra 2014a for limitations.

	Contour band	Numbers of people within contour band	Total Cost per person for mid value in decibel band	Estimated cost
24-hour	55-60 dB Lden	757,400	£30.29	£22,941,530.05
	60-65 dB Lden	188,600	£47.61	£8,979,063.05
	65-70 dB Lden	52800	£65.29	£3,447,256.72
	70-75 dB Lden	7100	£83.34	£591,695.98
	>75 dB Lden	100	£90.66	£9,066.19
			Total cost	£35,968,611.99

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