Noise & Health –
Valuing the Human Health Impacts of Environmental Noise Exposure

A Response By
The Interdepartmental Group on Costs and Benefits Noise Subject Group (IGCB(N))

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Contents

Executive Summary

1. Noise, defined as any unwanted sound, is associated with a wide range of adverse impacts on human health, public amenity, local ecology, and productivity. Managing noise effectively and efficiently requires a detailed knowledge of these impacts so that they can be balanced against other considerations.

2. At present, the economic valuation of noise pollution in the UK is primarily focused on the amenity impacts, defined as the conscious negative reaction to noise. Currently the approach to valuing noise in the UK focuses on amenity[1] impacts though the Department for Transport's "WebTAG" values for annoyance, derived from hedonic pricing analysis that examines the impact on property prices of households' exposure to noise[2], representing only part of the total valuation of the impacts of noise. As a result, the Interdepartmental Group on Costs and Benefits noise subject group (IGCB(N)) was established with the remit to develop and disseminate best practice economic approaches to value the impact of changes in noise.

3. In September 2008, the first report of the IGCB(N) identified the impact pathway approach as the central methodology for appraisal of noise[3]. This approach follows the logical progression from identifying the source of the noise, followed by modelling of how the noise is dispersed to estimate the population affected, through to the quantification and monetisation of observed impacts. The report identified four broad groups of impacts resulting from noise on health, amenity, productivity, and ecosystems.

4. Of these four groups, the IGCB(N) identified health impacts as a priority area for further research, based on importance of impacts, value added, availability of evidence and links to existing data. These criteria were selected as key attributes which are seen to determine the likelihood of success in contributing to building an appraisal methodology. A key factor in this decision was the major progress of the literature in linking noise and health. Indicative analysis also found that health impacts could potentially be as large as £2-3 billion per annum, a cost which is absent from the current evaluation framework.

5. In October 2008, Defra, on behalf of the IGCB(N), commissioned experts Dr Bernard Berry and Dr Ian Flindell to undertake a review of research into the links between noise and health. The four key aims of this research were to:

- Identify a comprehensive list of potential adverse health impacts from noise and review the current state of evidence for each of those impacts[4];

[1] Throughout this response, the term "amenity" will be used interchangeably with "annoyance" as the IGCB(N) considers annoyance to be a subset of amenity impacts. Appraising amenity impacts as opposed to annoyance impacts allows for the benefits of quiet areas to be appraised on an equal policy footing as the costs of increased noise. Noise annoyance is defined by the World Health Organisation (WHO) as "a feeling of displeasure evoked by noise".

[2] Bateman, I.J., Day, B.H., & Lake, I. (2004), "The Valuation of Transport-Related Noise in Birmingham", *Department For Transport*
http://www.dft.gov.uk/stellent/groups/dft econappr/documents/divisionhomepage/032865.hcsp

[3] Available from www.defra.gov.uk/environment/quality/noise/igcb/documents/igcb-first-report.pdf

[4] It must be noted that in reviewing the literature, the broad World Health Organisation definition of health was applied, referring to "*a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity*". Therefore the scope of this report was wider than if a more restrictive definition had been used.

- Where a robust evidence base existed, recommend quantitative analysis (in the form of "dose-response functions") linking the impacts of noise to health, which could be applied in the UK;

- Identify any emerging adverse health impacts that should be kept under review for future consideration in evaluation; and

- Identify any structural challenges to developing and maintaining strong quantitative links between noise and health outcomes.

6. The research was published on 6 July 2009. Several key findings emerged:

- Strong empirical evidence was identified linking nose to acute myocardial infarction (AMI) (heart attacks) and other cardiovascular illnesses.

- Some evidence was found between noise and other health effects, including annoyance, mental health, hypertension (high blood pressure), sleep disturbance, cognitive development in children and hearing impairment. However, evidence around the monetary valuation of these impacts found in these studies (e.g. amenity) was not judged to be sufficiently robust to be directly used to monetise noise impacts.

- Several structural barriers were suggested to explain why consensus around a single dose-response function for any of these of noise impacts based on health effects may be delayed or prevented.

- The review has also highlighted a number of non-health impacts that may arise from noise. For example, sleep disturbance/loss caused by excessive noise may have negative impacts on both productivity and amenity.

7. The IGCB(N) welcomes this research. The purpose of this paper is to set out how it recommends this evidence be used. The key aim is to establish evaluation methodologies to reflect the available evidence quantitatively, and where possible, to inform policy decisions through appraisal. In response to these findings, the IGCB(N) recommends:

a) **Acute myocardial infarction (AMI) can be applied into monetary valuation of noise using the 2006 Babisch dose-response function.** Including this health impact will be a major step forward in the valuation of road traffic and industrial noise. Accordingly, the IGCB(N) is recommending the use of the Babisch curve to assess the additional risk of AMI with rising noise levels and has generated a methodology which monetises this risk (see Annex A of this document). However, policymakers using this methodology must be mindful of the uncertainties previously highlighted.

b) **The use of the IGCB(N)'s indicative quantification of hypertension and sleep disturbance impacts to reflect the associated risks in these areas.** Dose-response functions identified can be used for sensitivity analysis in policy appraisal, but evidence is not sufficiently developed to monetise these quantified effects. These impacts will instead be presented as the additional risk of incidences given marginal rises in environmental noise levels.

c) **The implementation of the 1990:1999 ISO standards by policymakers across government in order to avoid hearing impairment impacts.** Given the unlikelihood that the high environmental noise level that would be required to trigger hearing impairment would be reached through government policy, a valuation methodology is not required.

d) **Continued use of the Department for Transport's WebTAG monetary values for the amenity impacts of noise.**

e) **Prioritising and monitoring policy-oriented research in areas where impacts are believed to be significant, but quantification not sufficiently developed to enable inclusion in the IGCB(N) methodology.** Specifically, the IGCB(N) will monitor developments in monetising hypertension and sleep disturbance impacts, and reconciling confounding factors in dose-response functions such as air quality impacts and self-selections bias.

f) **Monitoring the progress of academic research in areas where impacts are not sufficiently proven or large pieces of research are required in order for links to be quantified.** Specifically, these impacts include impaired cognitive development in schoolchildren, detriment to mental health and approaches to quantifying amenity losses.

g) **Responding (where appropriate) to the structural barriers identified in the research.** In many cases, the IGCB(N) is not an appropriate body to address such challenges but may be able to support any measures to mitigate them.

8. The use of dose-response functions is recommended by the IGCB(N) as a pragmatic and robust means by which to quantify these impacts of noise. However, there are several uncertainties and sensitivities around the creation of these functions that must be noted in their use.

- Uncertainties within the academic literature in generating the dose-response functions include assumptions made in the meta-analysis used in order to align studies, the assumption that correlation between health impacts and noise levels implies a causation (as the physiological root of health effects is not conclusively proven), and confounding factors such as air pollution and self-selection bias. In addition, a static dose-response function may inadequately measure the dynamic effects of noise (i.e. habituation or increased sensitivity to impacts following long-term exposure).

- Other uncertainties are based on the pragmatic assumptions made by the IGCB(N) in order that these dose-response functions can be used in appraisal, for example, in estimating the prevailing probability of impacts, the use of fixed marginal values to simplify variances in effects due to differing dispersion, and the assumption of equivalency across noise metrics. The IGCB(N) has assumed, where necessary, a common dose-response function across different noise sources (e.g. modes of transport, industrial), though it is likely that the noise (and therefore the impact) disperses in different ways.

9. Given the expanding literature on noise and health, the IGCB(N) will actively monitor developments in research in order to address these uncertainties and reflect the latest developments in identification and quantification of impacts to improve the valuation of noise. The results of this work on health impacts need to be placed in the wider context of the evaluation of noise, for example, the priorities of evaluating productivity and amenity impacts and valuing quiet areas.

Chapter 1: Introduction

Issue

10. The first report of the Interdepartmental Group on Costs and Benefits noise subject group (IGCB(N)) highlighted the increasing body of evidence on noise pollution and its detrimental impacts on human health, amenity, ecosystems and productivity[5]. Currently the approach to valuing noise in the UK focuses on amenity[6] impacts. To manage noise effectively and efficiently requires knowledge of the scale and level of the associated social costs.

11. At present, policymakers seeking to appraisal noise impacts of policy can use the Department for Transport "WebTAG" guidance, which value annoyance costs for transport noise. Values for noise annoyance[7] have been estimated based a programme of research that was commissioned by the Department for Transport[8] together with a review of international evidence and benefits transfer analysis[9]. The basis of these values is hedonic pricing analysis that examines variation in house prices depending upon exposure of households to noise. While amenity constitutes a significant proportion of the total impacts of noise, it does not reflect the total impact as it excludes a range of other impacts. The IGCB(N) was established with the remit to develop and disseminate best practice economic approaches to value the total impact of changes in noise.

12. The core objective of the IGCB(N) is to develop, maintain and disseminate a methodology for producing tools which inform decisions that impact upon noise. This report sets out how the latest research on the links between noise and health will be incorporated into the IGCB(N) methodology. The IGCB(N) will continue to actively monitor research into the health impacts of noise, seeking to continually incorporate the latest developments into its methodology in order to best reflect the scale of the impacts.

Background

13. Noise is a pervasive and growing problem both within the UK and across Europe. In May 2007, a survey by the UK National Society for Clean Air showed that noise had a 'major impact' on 45% of respondents, compared with 35% a year earlier. Meanwhile, figures from the Office for National Statistics indicate that noise complaints to local government offices have more than doubled over the past decade[10].

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[5] First Report of the Interdepartmental Group on Costs and Benefits Noise Subject Group (IGCB(N)) (2008) "An Economic Valuation of Noise Pollution – Developing a Tool for Policy Appraisal" www.defra.gov.uk/environment/quality/noise/igcb/documents/igcb-first-report.pdf

[6] Throughout this response, the term "amenity" will be used interchangeably with "annoyance" as the IGCB(N) considers annoyance to be a subset of amenity impacts. Appraising amenity impacts as opposed to annoyance impacts allows for the benefits of quiet areas to be appraised on an equal policy footing as the costs of increased noise.

[7] Noise annoyance is defined by the World Health Organisation (WHO) as "a feeling of displeasure evoked by noise".

[8] Bateman, I.J., Day, B.H., & Lake, I. (2004), "The Valuation of Transport-Related Noise in Birmingham", *Department For Transport* http://www.dft.gov.uk/stellent/groups/dft econappr/documents/divisionhomepage/032865.hcsp

[9] Nellthorp, J., Bristow, A., & Mackie, P. (2005) "Developing Guidance on the Valuation of Transport-Related Noise for Inclusion in WebTAG" *Department for Transport*

[10] http://www.statistics.gov.uk/StatBase/ssdataset.asp?vlnk=7295&Pos=1&ColRank=1&Rank=272

14. Indicative estimates produced by the IGCB(N) suggest that noise pollution imposed a social cost[11] on England in 2008 in excess of £9 billion per annum[12]. This estimate comprises £5-9 billion in annoyance costs, health costs of around £2 billion, and productivity losses costing another £2 billion.

15. To manage noise efficiently, it is essential that there is a consistent, pragmatic and comprehensive economic valuation methodology to inform decisions. In principle, this evidence base should quantify all of the impacts of noise management by estimating the costs and benefits of policy interventions. However, current valuations of noise focus on amenity and omit other potential impacts, which may mean that the benefits from noise management policies in abating noise levels are underestimated. The scale of the omissions is unknown but the indicative analysis above suggests the current approach could undervalue the costs of noise by 50%.

16. The first report of the IGCB(N) identified the impact pathway approach as the central framework that the IGCB(N) would employ to create a noise evaluation methodology to reflect the social consequences of changes in noise. This approach involves following the noise from its source (such as a vehicle or industrial facility), to the resulting ambient noise levels (including consideration of the volume, pitch and duration) onto a receptor (the general population). This is then used to estimate a range of impacts (such as adverse health effects), which are then monetised. The main steps of the impact pathway approach are outlined below:

- Quantification of emissions of noise from a range of different sources;
- Conversion of projected change to noise levels into estimated population exposures to noise;
- Quantification of health and non-health impacts associated with the change in noise;
- Valuation (monetisation) of these impacts; and
- Description and analysis of uncertainties associated with the quantification and valuation of impacts.

17. The first two stages of this approach have already been undertaken at a broad level in 2008 as part of the noise mapping exercise, which ensured compliance with the European Commission's Environmental Noise Directive (END). However, estimation of consequences of changes in exposure to noise would be required for appraisal of specific policies. Guidance is already available regarding estimation of changes in exposure to noise resulting from, for example, transport plans and policies, but there are many more impacts to consider.

18. The evidence has suggested links between noise and a wide range of impacts, which can be categorised into four broad groups[13], namely:

[11] However, appraisal of the costs of policies to reduce noise would be required in order to reach a conclusion regarding whether these social costs of noise are excessive.
[12] The process of developing this estimate is provided in Annex A of the first IGCB(N) report available from www.defra.gov.uk/evidence/economics/igcb/index.htm.
[13] It should be noted that these four groups may overlap to some extent. The decision to separate these impacts into groups is mainly for presentational purposes; some impacts (such as sleep disturbance or amenity) may feasibly fall into multiple groups, a fact that the IGCB(N) will be mindful of so as to avoid double-counting of impacts.

- Health impacts, including long-term health effects such as changes in mortality and temporary effects such as acute myocardial infarction (heart attacks);

- Public amenity, which reflect the public's conscious annoyance from noise exposure;

- Productivity losses, including tiredness through sleep disruption, or daytime noise distraction, which reduces work output or quality; and

- Environmental impacts, where noise levels may disrupt the functioning of ecosystems, for example, by disturbing breeding patterns.

19. Of these four groups, health impacts were identified as the priority area for further research based on four criteria: importance, value added, existing state of evidence and likelihood of success[14]. The IGCB(N) has estimated that health impacts have the potential to account for £2-3 billion in detriment each year[15] that is unaccounted for in the current appraisal framework. Aligned to this, there has been major progress in the literature on linking noise and health, creating a strong potential that further research would be successful in identifying a robust quantitative link. Concern over the potential scale of environmental noise impacts prompted the 6-year study of noise and health impacts by the Ad Hoc Experts Groups formed by Defra and the Health Protection Agency in 2004. The recently published report by the Ad Hoc Experts Group, "Environmental Noise and Health in the UK"[16]¸ has identified several health impacts commonly agreed in noise and health literature.

20. To reflect health impacts, it is necessary to identify a quantitative link between marginal changes in noise levels and health outcomes. Such functions are commonly referred to in the literature as "dose-response functions". In August 2008, the IGCB(N) commissioned an external review to identify and peer-review existing literature on the health impacts of noise and the relevant dose-response functions.

Estimating Dose-Response Relationships between Noise Exposure and Human Health Impacts in the UK

21. On 28 October 2008, Bernard Berry of Berry Environmental Ltd, in association with Dr Ian Flindell of Ian Flindell Associates, was commissioned to undertake this research. A number of advisors supported the central team, including: Dr Rokho Kim of the World Health Organisation European Centre for Environmental Health (ECEH), who acted as a special adviser to the project; consultant Nicole Porter, who provided evidence on dose-response relationships for noise-induced sleep disturbance and contributed to the evaluation criteria; John Bates, who provided statistical support; and Professor Graham Loomes of the University of East Anglia, who provided economic input.

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[14] Likelihood of success in this context relating to the probability that research would have a positive impact on policy appraisal

[15] First Report of the Interdepartmental Group on Costs and Benefits Noise Subject Group (IGCB(N)) (2008) "An Economic Valuation of Noise Pollution – Developing a Tool for Policy Appraisal"
www.defra.gov.uk/environment/quality/noise/igcb/documents/igcb-first-report.pdf

[16] Health Protection Agency (2009), "Environmental Noise and Health in the UK"
http://www.hpa.org.uk/webw/HPAweb&Page&HPAwebAutoListName/Page/1246433632961

22. This research aims to address gaps in the methodology for valuing the health impacts of noise in the UK and ultimately enable the IGCB(N) to develop a robust and practical framework. As such, there are four key aims of the research:

- To identify the potential adverse health impacts from exposure to noise, and to review the current state of evidence for each of those impacts;
- Where a robust evidence base exists, to develop dose-response functions for the health-related impacts of noise which could be applied to policy appraisal in the UK;
- To identify emerging evidence on adverse health impacts that should be kept under review; and
- To identify any structural challenges to developing academic consensus around a single robust dose-response function for any health impact of noise.

23. To achieve these objectives, this research undertook a two-stage literature review of the existing evidence on the links between noise and health:

Stage 1: Reviewed the links between exposure to noise and a comprehensive list of health outcomes[17]. Health impacts include annoyance, detriment to mental health, cardiovascular and physiological impacts (including ischemic heart disease and hypertension), night-time effects (including disruption of sleep patterns, increased awakenings, reduced sleep quality, next-day and long-term productivity losses), impaired cognitive development in schoolchildren, and hearing impairment. Based on a number of evaluation criteria for each research study[18], this review identified a subset of health impacts for more detailed study.

Stage 2: Undertook a detailed analysis of the key health outcomes identified for further research in Stage 1, namely cardiovascular effects, hypertension and sleep disturbance. For each of these areas, a comprehensive literature review was undertaken to identify which existing evidence linking noise and health might be used to inform policy decisions. This work was supplemented by consultations with a number of international experts.

[17] At this stage a broad definition of 'health' was used. For presentational reasons, several of these were later categorised within other groups of impacts as the review developed.

[18] The criteria were: a) the relevance, statistical representativeness, and measurement accuracy of the dose, or input variables, measured; b) the relevance, statistical representativeness and measurement accuracy of the response, or outcome, variables measured; c) the range of applicability to other types of noise exposure and/or environment; d) the range of applicability to other adverse health effects; e) the statistical strength of the observed dose-response relationship; f) the relative absence of potential confounding variables; and g) the scientific plausibility of the observed dose-response relationship considered in terms of known or theoretical biological mechanisms.

24. This research was published on 6 July 2009[19]. The key findings were:

- Strong evidence was identified linking exposure to noise to acute myocardial infarction (heart attacks) and other cardiovascular effects. Such effects could be quantified on the basis of existing evidence by Babisch[20] in Germany and van Kempen et al.[21] in the Netherlands.

- For some health effects, such as annoyance, mental health, hypertension, sleep disturbance, cognitive development and hearing impairment, the statistical evidence was not judged sufficiently robust to be able to incorporate fully into policy appraisal.

- Several structural barriers were suggested to explain why consensus around a single dose-response function for any of these of noise impacts based on health effects may be delayed or prevented.

- A number of what some may consider to be non-health impacts were also identified, such as sleep disturbance, which could result in a loss of productivity and amenity.

General reaction

25. The IGCB(N) welcomes this report as providing a major step to progress its objective of developing a robust and rigorous approach to evaluating noise. The research was comprehensive in its analysis of both current and upcoming research.

26. The use of dose-response functions is recommended by the IGCB(N) as a pragmatic and robust means by which to quantify these impacts of noise. However, there are several uncertainties and sensitivities around the creation of these functions that need to be noted by policymakers when using them:

- The dose-response function identified to quantify AMI is based on meta-analysis of multiple studies. Bringing together such a range of different studies is rarely straightforward; therefore assumptions will have been made in order to align the methodologies.

- Various pragmatic assumptions have been made by the IGCB(N) to enable these dose-response functions to be adapted into a useable appraisal tools, for example, in estimating the prevailing probability of the impact, the use of fixed marginal values to simplify the difficulties associated with differing impacts due to variations in dispersion of noise, the assumptions of equivalency across multiple noise metrics in order that the dose-response function can be related to the metric currently used in government policy appraisal.

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[19] Berry, B. & Flindell, I. on behalf of the Interdepartmental Group on Costs and Benefits Noise Subject Group (IGCB(N)) (2009) "Estimating Dose-Response Relationships between Noise Exposure and Human Health in the UK" http://www.defra.gov.uk/environment/quality/noise/igcb/publications/healthreport.htm

[20] Babisch, W. (2006) "Transportation Noise and Cardiovascular Risk, Review and Synthesis of Epidemiological Studies, Dose-Effect Curve and Risk Estimation", *WaBoLu-Hefte 01/06, Umweltbundesamt*

[21] van Kempen, E. Staatsen, B. & van Kamp, I. (2005) "Selection and evaluation of exposure-effect relationships for health impact assessment in the field of noise and health", RIVM report 630400001/2005

- Dose-response functions indicate a statistical link between noise and the identified impact, but do not necessarily imply a direct causation. However, the types of impacts discussed in this report are widely accepted by academics and experts in the field to arise from environmental noise exposure. There is a lack of consensus around a physiological explanation of how noise causes health impacts, which thus may not be fully captured by the dose-response function or the chosen noise metric. Additionally, confounding factors such as self-selection bias (where individuals may choose to live or move away from noisy areas based on their susceptibility) and air pollution (which often arises from the same source as the noise pollution) mean that the dose-response function may capture effects associated with noise other than the direct health impact.

- A single dose-response function may inadequately measure noise impacts arising from different sources (e.g. modes of transport, industrial) as they disperse noise (and therefore impacts) differently.

- The dose-response function is a static tool; however, there are possible dynamic effects of noise based on the length of exposure to noise sources which may be being ignored. However, these effects of long-term exposure are unknown (i.e. whether the population becomes habituated to these impacts, or their effects increase over time).

27. The methodology applied in this research has developed clear, objective and defensible criteria to evaluate the appropriateness of the evidence (such as dose-response functions) reviewed in informing policy decisions. The seven criteria cover the measurement of the dose, response, source, range, strength, confounding factors and plausibility.[22] There is scope to use these criteria more widely, for example, where evidence is developed linking environmental factors with health outcomes.

28. Though the physiological causality of noise impacts or the accuracy of the dose-response functions used in describing the relationships between noise and its impacts are not unanimously proven, inclusion of these impacts is recommended by the IGCB(N) in line with the “precautionary principle”. Considering the balance between delaying the use of this methodology and failing to abate these impacts against the risk of distorting appraisal with potentially inaccurate figures, a high level of stringency was sought when identifying research for IGCB(N) consideration to minimise the latter; Berry and Flindell required a level of robustness when considering the dose-response function (through their seven criteria) that is relatively severe when compared against studies that have previously been accepted for inclusion in government appraisal methodology e.g. studies driving the assessment of value of technology.

[22] These criteria are discussed in more detail in the technical report. Berry, B. & Flindell, I. on behalf of the Interdepartmental Group on Costs and Benefits Noise Subject Group (IGCB(N)) (2009) “Estimating Dose-Response Relationships between Noise Exposure and Human Health in the UK”
http://www.defra.gov.uk/environment/quality/noise/igcb/publications/healthreport.htm

29. The Berry and Flindell literature review was met with general support when presented at an international conference of noise experts and economists, suggesting that these impacts are widely accepted and have not been overstated. This view is further supported by the number and range of papers on the health effects of noise, presented by other international experts at the same event, including one concerning a methodology to be used in France for assessing the health impacts of developments in transport infrastructure[23].

30. The "impact pathway" methodology, which links noise to outcomes that are then valued, was reviewed as part of this work and was supported by the academic community. Expert in economic evaluation Professor Graham Loomes (University of East Anglia) has stated that:

> *"given the current state of knowledge, an economic evaluation along the lines indicated above [IGCB methodology], and with appropriate checks for sensitivity to different assumptions, would appear to be entirely feasible and, arguably, highly desirable".*

31. The combination of reviewing literature for both scientific robustness and practical application is also seen as a major strength. The report also reviews evaluation across Europe both where health is included in the evidence base and how it has been applied.

32. Detailed reactions to the key findings of this research can be found in the remainder of this document.

[23] Baulac, M. Bourgois, D. Marry, S. Defrance, J. & Goeury, C. (2010) "Elaboration of a methodology for the definition of an indicator of health risk induced by noise in urban areas", *Internoise 2010*

Structure of response

33. This document sets out how the IGCB(N) intends to utilise the results of this literature review to create an evaluation methodology. The structure of the remainder of this report is as follows:

> **Chapter 2** explains the evidence linking noise levels and cardiovascular disease, presents the derived dose-response function, and explains the steps the IGCB(N) is taking to incorporate this impact into policy appraisal.
>
> **Chapter 3** gives more information on the other health effects studied where evidence was not considered sufficiently robust to incorporate into policy appraisal, including dose-response functions for indicative use only.
>
> **Chapter 4** provides information on evidence on the productivity and amenity impacts of noise.
>
> **Chapter 5** explains the structural barriers to academic consensus around dose-response functions for noise impacts (thus delaying their use in policy appraisal) and the IGCB(N)'s views on what can be done to reduce or remove them.
>
> **Chapter 6** summarises the conclusions of this report and sets out the ongoing work by the IGCB(N) to develop tools to evaluate changes in noise.

Chapter 2: Dose-response relationship for cardiovascular effects

34. Of the impacts considered in the research, the strongest link was seen to be between noise levels and cardiovascular disease. This chapter provides an overview of how the IGCB(N) recommends the reflection of this evidence in evaluation and appraisal.

Cardiovascular effects – research findings

35. The review identified the studies carried out by Babisch (2006)[24] in Germany and van Kempen et al. (2005)[25] in the Netherlands as most robust assessments to date of a quantitative link between exposure to noise and an increased risk of acute myocardial infarction (heart attack). The first recommendation of the review therefore states that:

> *"It is concluded that the dose-response relationship proposed by Babisch in 2006 between Lday and Acute Myocardial Infarction provides an adequate basis for a methodology to value health effects."*[26]

36. The authors state that the Babisch study represents the most comprehensive analytical review looking at the links between noise and acute myocardial infarction (AMI). In developing a dose-response relationship between road traffic noise and the risk of AMI, Babisch has used a meta-analysis comprising five analytical and two descriptive studies, which were selected using stringent criteria from the existing literature. Assumptions were made by Babisch in order to align these studies to develop a dose-response function mapping the association between noise levels and the risk of AMI; a summary of the paper can be found in the Berry and Flindell literature review[27]. The meta-analysis concluded that as noise levels rise above 60 LAeq, the risk of AMI increases monotonically[28].

37. Based on this, a common risk curve is derived for the relationship between road traffic noise – expressed in L_{day} – and the incidence of AMI, showing that:

- Below daytime road traffic sound levels of 60 LAeq (L_{day}: 6-22 hr), no increase in AMI risk could be detected.
- For sound levels greater than 60 LAeq, the AMI risk increases continuously, with relative risks (odds ratios) ranging from 1.1 to 1.5, with reference to a baseline of ≤60 LAeq.

38. The dose-response function derived by the Babisch study is shown in Figure 1 below, representing the percentage increase in the risk of AMI given an increase in noise levels above a 55 decibel baseline.

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[24] Babisch, W. (2006) "Transportation Noise and Cardiovascular Risk, Review and Synthesis of Epidemiological Studies, Dose-Effect Curve and Risk Estimation", *WaBoLu-Hefte 01/06, Umweltbundesamt*

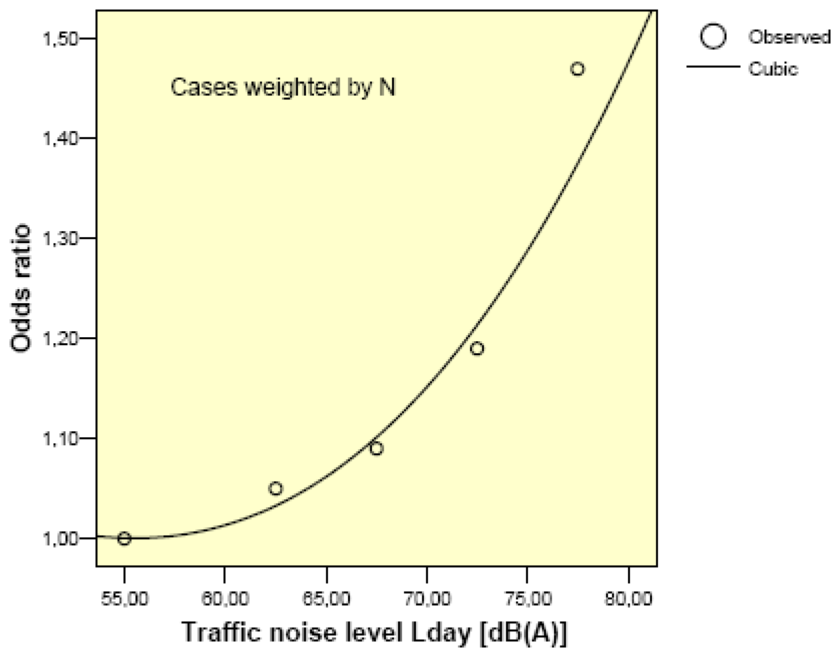
[25] van Kempen, E. Staatsen, B. & van Kamp, I. (2005) "Selection and evaluation of exposure-effect relationships for health impact assessment in the field of noise and health", RIVM report 630400001/2005

[26] "Estimating Dose Response Relationships between Noise Exposure and Human Health Impacts in the UK: Technical report", page 151.

[27] "Estimating Dose Response Relationships between Noise Exposure and Human Health Impacts in the UK: Technical report", page 39.

[28] A "monotonic" probability function in this instance can be defined as one where the probability of the variable studied (i.e. AMI) is continually increasing with rising noise levels.

Figure 1. Babisch curve, linking noise levels and AMI



39. The Babisch curve has been extensively peer-reviewed since its publication. In addition to the peer review conducted by the authors, an independent statistical advisor was asked to critically evaluate the Babisch review, and has confirmed the statistical robustness of the analysis. His report did not note any significant problems with the work but did raise a few minor questions.

40. The reviewer noted a number of uncertainties within the Babisch curve, which users of the IGCB(N) evaluation methodology should be made aware of:

- There are large statistical uncertainties associated with the increasing relative risk of AMI observed as road traffic sound levels rise. These uncertainties might reflect underlying variability, such as differences in individual susceptibility, or uncertainties in measuring the dose and effect variables.

- The Babisch curve was derived from a meta-analysis comprising only road traffic noise studies, meaning the curve has limited applicability against other noise sources. To make use of the curve for aircraft noise, for example, one would have to assume the same dose-response relationship. This is unlikely to be the case, for several reasons. Babisch noted that aircraft noise acts on all sides of a building, unlike road traffic noise, suggesting that the AMI risk induced by aircraft noise could be greater.

- None of the research which has been published to date has been able to resolve the confounding effect of correlated levels of air pollution, which has similar negative health impacts.

- There are other potential confounding factors that were not possible to take into account. For example, the possibility of self-selection bias, when individuals of differing susceptibilities might have chosen (or conversely were unable to choose) quieter or noisier areas as places to live, cannot be ruled out.

- Though the Babisch curve highlights a statistical relationship between environment noise levels and risk of AMI, there is no accepted biological or physiological explanation of how they are linked.

- No research to date has been able to identify which particular features of environmental noise (if any) are the most damaging to health. There has not yet been any scientific justification for the assumption that long-term average outdoor sound level metrics such as LAeq and Lden provide an adequate description of the most important features of environmental noise assumed to be responsible for these impacts.

41. Despite the uncertainties behind the use of dose-response functions, both the IGCB(N) and the authors of the literature review believe that there is a greater potential for distorting policy appraisal by not using these dose-response functions and hence failing to include these noise impacts, than by including potentially inaccurate figures. In line with the precautionary principle, to wait until these dose-response functions were agreed beyond a doubt within the academic community would impose societal costs (in terms of delaying the inclusion of these health impacts into appraisal) greater than the risk that the quantification of the impacts is potentially inaccurate.

IGCB response

42. The finding that the Babisch curve is an appropriate tool for the appraisal of noise across government is a key conclusion of the report. While uncertainties remain around the identified function, with these kept in mind, the IGCB(N) recommends the use of this function in policy appraisal as appropriate. This section sets out how the IGCB(N) is supporting the use of this curve.

43. In keeping with the existing approach to valuing the amenity impacts of noise, the IGCB(N) recommends the use of marginal values of health impacts per household per decibel (dB).

44. To develop these values using the identified function for the appraisal of noise, it is necessary to make four key assumptions, namely:

i. In order to link Babisch's methodology to the IGCB(N)'s evaluation methodology, it has been assumed that the road traffic noise level Lday 16hr used by Babisch is equivalent to the current measurement of noise used for policy appraisal of LAeq, which is Lday 18hr dB(A). While these two measures are not entirely consistent, there exists sufficient comparability between them to ensure that such an equivalency is realistic.[29]

[29] Assumption set out in page 149 of the technical report.

ii. The prevailing probability of AMI is based on an average probability of 0.0084% per person in the UK. This value has been derived based on the 6,313 cases of AMI in London occurring in 2006 across a population of 7.5 million.[30]

iii. The cost of a single instance of AMI is estimated based on the recommended QALY value of £60,000, the evidence that 72% of cases of AMI lead to immediate mortality (with an estimated life expectancy loss of 11 years)[31] and a disability weight of survival from AMI of 0.405[32] (consistent with World Health Organisation (WHO) figures).

iv. An average of 2.4 persons per household. This assumption is estimated on the basis of the total UK population compared to the housing stock.

45. Combining the identified dose-response function with these assumptions, the marginal cost of increased risk of AMI as a result of rising noise levels can then be calculated. Annex A provides a comprehensive overview of the methodology applied to estimate these values and includes a full list of the marginal costs for each 1 dB increase in noise above 55 dB. Table 1 below provides a summary of the marginal health costs (based on AMI) of rising noise levels, and for comparison the associated amenity costs, which form the current valuations of noise.

[30] Sources of data provided on page 147 of the technical report.
[31] ONS mortality statistics (2005) www.statistics.gov.uk/statbase/Product.asp?vlink=620
[32] World Health Organisation (2004) "Global Burdens of Disease 2004 Update: Disability Weights for Diseases and Conditions"
http://www.who.int/healthinfo/global_burden_disease/GBD2004_DisabilityWeights.pdf

Table 1: Valuation of AMI impacts of noise

Volume LAeq, 18hr dB(A)	Additional risk of AMI	Cost per household per dB change		
		Health value	Current value (amenity/annoyance costs only[33])	% change in costs (from inclusion of health costs)
55 – 60 dB	0.00010%	£2.70	£40.00	+ 6.75%
60 – 65 dB	0.00168%	£10.47	£53.20	+ 19.68%
65 – 70 dB	0.00336%	£15.71	£66.40	+ 29.29%
70 – 75 dB	0.00504%	£29.62	£79.60	+ 37.21%
75 – 80 dB	0.00720%	£41.01	£92.80	+ 44.19%
80 – 85 dB	0.039%	£53.60	£98.00	+ 54.7%

Note: *Mid-point marginal values are used for each volume range.*

46. Table 1 shows that including the impact on human health through the increased risk of AMI significantly increases the monetary cost associated with increases in noise above 55 dB. The increase in costs in response to rising noise levels is non-linear; a rise in costs of under 10% at low levels sharply rises to a cost increase of 50% at high noise levels.

47. Based on this research and the assumptions above, the IGCB(N) recommends the use of these estimated values for road and industrial noise pollution.

48. In using these values, it is important to reflect the uncertainties surrounding these estimates, including those surrounding the assumptions set out above and the dose-response function. The IGCB(N) will continue review the evidence underpinning these calculations. Particular consideration should be given to:

- The source of the noise, as different noise sources produce distinct types of noise and therefore may have different impacts;
- The metric by which noise is measured, as noise is measured in a variety of ways and so it is important to use the appropriate measure. The above health costs are calculated given a specific measure (LAeq) and so are not applicable to alternate measures;

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[33] WebTAG Supplementary Guidance: Valuation of Transport-Related Residential Noise, *Department for Transport* http://www.dft.gov.uk/webtag/documents/expert/doc/unit3.3.2-supplementaryguidance.doc

- The differing sensitivities to the health impacts of noise by different receptors (i.e. populations), as the health values are averaged estimates; and
- Specific instances where these values cannot be applied, in which circumstances, the justification should be explicitly set out within the relevant analysis.

Chapter 3: Other potential health impacts

49. In reviewing the literature on the potential links between noise and health, the research has yielded important results in indentifying key health impacts. In some areas this research was not seen to be in necessarily robust to allow economic valuation. This section considers the findings of the research on those health impacts identified other than cardiovascular effects (AMI) in order to identify future areas of work.

Other health effects – research findings

50. The other health effects reviewed in the research were hypertension (high blood pressure), hearing impairment, and mental health effects. Where possible, indicative dose-response functions were recommended and these are also presented below. Other impacts such as annoyance, sleep disturbance and impediment to cognitive development in children, which were initially investigated as health impacts, in this response have been categorised as amenity and productivity impacts respectively. These are discussed in the next chapter.

Hypertension

51. The review indicated that, although there have been new and interesting results linking noise and hypertension and additional analyses such as the European Commission's Hypertension and Exposure to Noise near Airports (HYENA) project[34], there is no firm agreement within the academic community on a single dose-response relationship. Figure 2 plots the results of five studies which link aircraft noise with hypertension, clearly illustrating the uncertainty.

52. Given this uncertainty, no single dose-response relationship that met all the criteria set out in this study was established. In July 2009, Babisch and van Kamp published a paper titled "Exposure-response relationship of the association between aircraft noise and the risk of hypertension"[35]. In spite of the inherent limitations, the authors provide a "best guess" estimate which could be used for quantitative risk assessment until more data become available.

53. This suggested approach relates aircraft noise and the risk of hypertension by using a calculated relative risk of 1.13 (i.e. a 13% increase in the risk of hypertension above the level of risk at the baseline) for each 10 dB(A) increase in L_{den}, above a baseline of 55 dB(A). This proposed exposure-response relationship has been peer-reviewed prior to inclusion in academic journal *Noise & Health*, and has been approved by Bernard Berry, though he did note considerable variation between the papers used in the study. For this reason, it is not recommended that this exposure-response relationship form part of the IGCB(N) evaluation methodology at this time.

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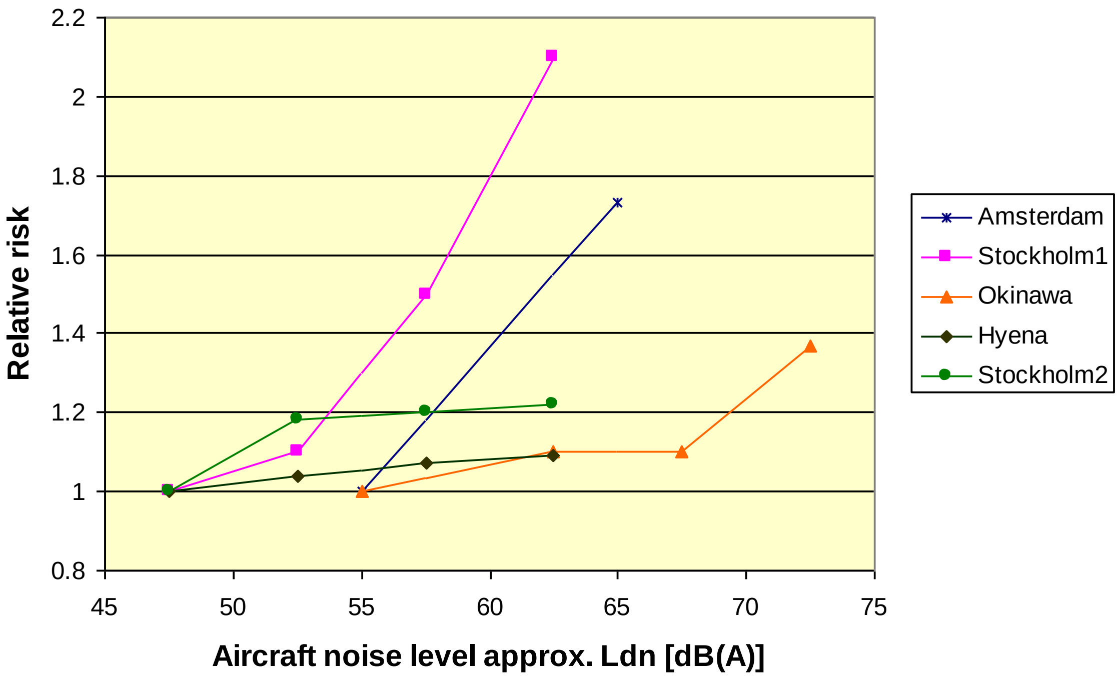
[34] For more information, visit http://www.hyena.eu.com.

[35] Babisch, W. & van Kamp, I. (2009) "Exposure-response relationship of the association between aircraft noise and the risk of hypertension", *Noise & Health,* 11 (4) p. 161-168

Figure 2. Comparison of hypertension studies.



Hearing impairment

54. The dose-response function for hearing impairment shows that typical sound levels of environmental noise are not high enough to cause any significant hearing loss. Further research is not necessary as established dose-response relationships for occupational hearing loss are already in use. The ISO 1990:1999 standard provides the methodology for calculating noise-induced hearing loss and is based on assessments under the UK's Control of Noise At Work Regulations 2005[36].

Mental health effects

55. A review by Irene van Kamp and Evan Davies[37] is identified by Berry and Flindell as the most recent and comprehensive research on this area. This review found that new evidence supported the conclusion that there is no direct association between environmental noise and mental health. Other research in this area similarly finds no quantitative link between noise and mental health. As a result, this impact was not considered in detail in the second stage of this work and is not recommended for inclusion in the IGCB(N) evaluation methodology.

[36] For more information, visit http://www.opsi.gov.uk/si/si2005/20051643.htm
[37] van Kamp, I. & Davies, E. (2008) "Environmental Noise and Mental Health: Five-Year Review and Future Directions", *9th International Congress on Noise as a Public Health Problem (ICBEN)*

IGCB response

56. The review of statistical links between noise and health outcomes is central to informing the future work of the IGCB(N) and prioritisation of potential areas of research. Given the absence of robust evidence, monetary valuation of the health effects identified in this chapter is not recommended. However, the IGCB(N) believes that, given that this report and the Ad Hoc Experts Group report[38] have both identified notable links between these health impacts and noise levels, it is important that relevant impacts are reflected in some way by decision-makers. Therefore, these impacts should be prioritised for future research, with the aim to include them in policy appraisal once the necessary evidence is available and once tools and guidance have been developed that allow the robust, proportionate and transparent application in appraisal.

57. The remainder of this section provides the IGCB(N) recommendations on how each of these three health effects may be reflected in evaluation of the impacts of noise.

Hypertension

58. Despite the growing evidence base on the links between noise and hypertension, there are currently major uncertainties that make quantification and valuation for policy decisions unacceptably uncertain. In light of the inability to identify a single exposure-response function that could be used for quantitative appraisal, the review instead identified an upcoming paper by Babisch and van Kamp that seeks to consolidate the existing research on aircraft noise and the risk of hypertension in order to provide a best estimate exposure-response function.

59. Following this review, this study linking noise to hypertension was published in *Noise & Health*[39]. This change was then discussed with the authors, who supported their recommendation to use this study to quantify impacts on hypertension while the evidence continues to develop. Therefore, the IGCB(N) is recommending the use of this dose-response function to quantify hypertension impacts. Given the subject of these studies being aviation noise, the use of this information should be used to evaluate changes in aviation noise. However this link may also be used as indicative for other sources of noise while evidence is being developed.

60. To allow the use of this dose-response function, the IGCB(N) has produced marginal estimates on the likely change in the incidences of hypertension with changing noise levels. In keeping with the values for AMI, these values are provides on a per household per decibel basis. Unlike the link to AMI, the values change linearly with noise levels.

61. Based on this dose-response function and additional assumptions, for each 1 dB(A) increase in Lden above 55 dB, the expected number of cases of hypertension increases by 1.16%. For example, if 1,000 houses were exposed to an increase of 1 dB(A) then we would expect 16 additional cases of hypertension. The basis of this calculation is set out in Annex C.

[38] Health Protection Agency (2009), "Environmental Noise and Health in the UK" http://www.hpa.org.uk/webw/HPAweb&Page&HPAwebAutoListName/Page/1246433632961

[39] Babisch, W. & van Kamp, I. (2009) "Exposure-response relationship of the association between aircraft noise and the risk of hypertension", *Noise & Health,* 11 (4) p. 161-168.

Hearing impairment

62. It is well established that exposure to high noise levels can lead to hearing impairment. However, the sound volumes necessary to trigger such an impact are unlikely to occur through exposure to environmental noise. These volume levels, where possible, would largely arise in work situations. As such, the ISO 1990:1999[40] standard evaluation methodology can be used, rendering an IGCB(N) approach unnecessary.

63. There may be potential gaps in the appraisal of hearing impairment impacts where the requisite high noise levels would be encountered, such as in specific leisure activities. In such instances where regulation is being considered, the IGCB(N) recommends that the impact on hearing impairment be reflected in accordance with ISO 1990:1999 standard methodology.

Mental Health

64. Given the evidence suggesting there is no link between noise and mental health, the IGCB(N) will not immediately undertake further research into this area. However, this does not exclude the possibility that the release of new evidence will necessitate future research.

[40] ISO 1990:1999 Acoustics - Determination of occupational noise exposure and estimation of noise-induced hearing impairment
http://www.iso.org/iso/catalogue_detail.htm?csnumber=6759

Chapter 4: Non-health impacts

65. Health effects are defined a number of ways by different groups. These definitions range from the broad World Health Organisation (WHO) definition of "*a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity; all factors that impact on wellbeing*" to the more restrictive definition of mortality and morbidity. In developing the IGCB(N) evaluation methodology into a presentational and analytical tool, the impacts of noise were separated into four groups: health, amenity, productivity and ecosystems. However, this categorisation should not be taken to dispute the wider definition of health, or the possibility of classifying these impacts in different ways.

66. Using the definition of health as morbidity and mortality, some areas studied in the review cannot be defined as health impacts, but should more appropriately be categorised under other endpoints in the impact pathway approach. This chapter details the results from the research for such areas: annoyance, sleep disturbance, and cognitive effects on children. The IGCB(N) response suggests suitable endpoints for these research areas as being productivity or amenity impacts.

Non-health impacts – research findings

67. The research undertook a comprehensive review of the effects of noise on health, including annoyance, sleep awakenings, self-reported sleep disturbance and detriment to cognitive development in children. This section summarises the findings in each of these areas.

Annoyance

68. The authors found that annoyance was highly subjective, as people vary in their sensitivity and susceptibility to environmental noise. At any given sound level, responses ranged from "highly annoyed" to "not annoyed at all", as well as all intermediate options. As a result, researchers have found it difficult to devise objective criteria for annoyance which could be used to inform monetary valuation.

69. While chronic annoyance from long-term exposure to noise may be a contributory factor to stress-related illness, in a similar manner it has proved difficult to measure.

70. Hence there is no consensus on how noise levels and annoyance might be quantitatively linked to health outcomes. As no robust dose-response function could be found, annoyance was not carried forward to the second stage of the review for more detailed investigation.

Sleep awakenings

71. Evidence on sleep awakenings was extensively reviewed as there is a considerable amount of published research in this area[41]. However, the wide range of dose and effect variables and experimental methods used by different studies makes comparison very difficult. In addition, interpreting research data on acute or transient sleep disturbances in terms of possible long-term adverse health effects is problematic. This is because occasional physiological responses to external noise stimuli are aspects of normal human behaviour and there is no *a priori* reason to suppose that they might be directly harmful.

72. One indisputable effect of excessive sleep disturbance is fatigue the following day. However, studies have yet to identify statistically significant associations between this fatigue and the transient disturbances to sleep directly caused by environmental noise.

73. It is therefore concluded that while it is well established that environmental noise can disturb sleep, there is not yet a consensus on a universal dose-effect relationship that could be used to assess the prevalence and severity of transient sleep disturbance arising from noise. There is also not yet a consensus on the extent to which any such disturbance may lead to longer term adverse health effects that could be used as a basis for monetary valuation of noise impacts.

Self-reported sleep disturbance

74. As the authors could not recommend a single dose-response relationship for use in assessing the scale of transient sleep disturbance health impacts, it was recognised that as a second best option, self-reported disturbance could be estimated (based on LA_{eq} at night). Based on the findings of the Berry and Flindell literature review, the most authoritative dose-response relationships currently available can be found in the 2004 European Commission (EC) position paper "Dose-effect relationships for night-time noise"[42]. This paper has technical uncertainties and limitations in its approach and the relationships did not meet the review's strict criteria; however, it was seen to be the best available quantitative link.

75. The functions in the EC paper are based on analyses of 15 datasets comprising over 12,000 individual observations of exposure-response combinations from 12 field studies, which include a questionnaire. The curves are based on data in the L_{night} (outside, maximally exposed facade) ranging 45 to 65 dB(A). Annex B contains polynomial functions calculated as close approximations of the curves in this range and their extrapolations to lower exposure (40-45 dB(A)) and higher exposure (65-70 dB(A)).

76. The functions for the Highly Sleep-Disturbed are shown in Figure 3 below:

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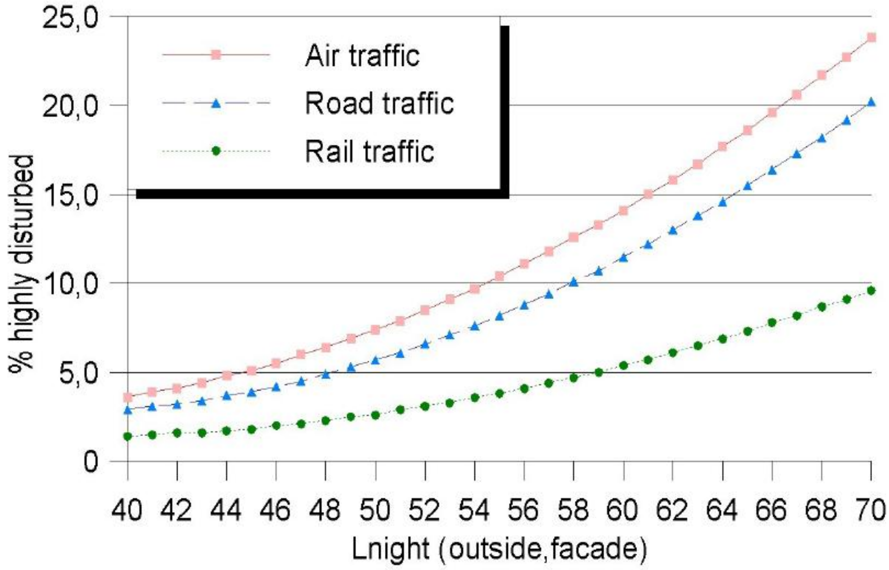
[41] Basner, M. Griefahn, B. & Muller, U (2009) "Practical Guidance for Risk Assessment of Traffic Noise Effects on Sleep", *Internoise 2009*
Basner, M. Griefahn, B. & Hume, K. (2009) "Sleep Disturbance Due to Noise: Key Research Issues for the Future", *Internoise 2009*
Basner, M. Brode, P. Griefahn, B. & Marks, A. (2009) "Cardiac Arousals Caused by Transportation Noise During Sleep", *Internoise 2009*
[42] European Commission Working Group on Health and Socio-Economic Aspects of Noise (2004) "Position Paper on Dose-Effect Relationships for Night Time Noise"
http://ec.europa.eu/environment/noise/pdf/positionpaper.pdf

Figure 3. Dose-response function showing the percentage of the study sample that is Highly Sleep-Disturbed as a result of night-time levels of road, rail and air traffic noise.



77. The EC paper notes that the above relationships represent the current best estimates of the influences of L_{night} on self-reported sleep disturbance for road traffic noise and for rail noise, when no other factors are taken into account. For aircraft noise, it notes that the variance in the responses is large in comparison to the variances found for rail and road traffic. This relative uncertainty means that the derived relationship between sleep disturbance and night-time aircraft noise should be considered as indicative.

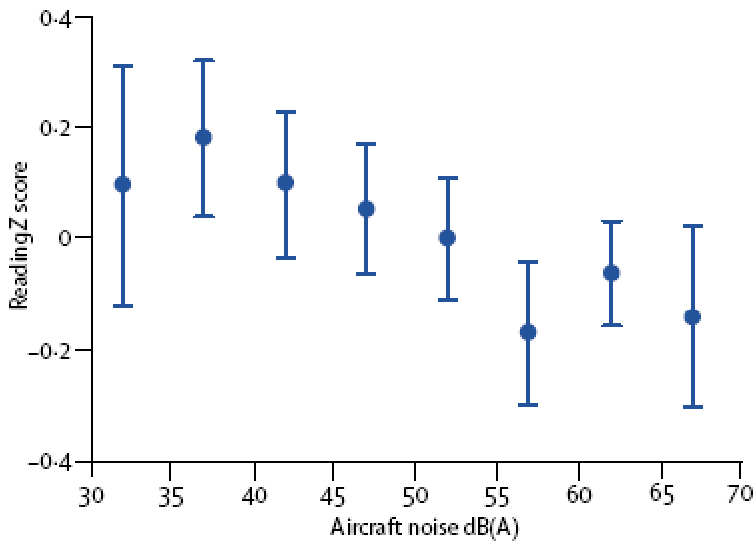
Cognitive effects on children

78. The review found research into the possibility that environmental noise at home and at school contributed to delayed cognitive development for children in a number of areas. There are a few key publications in this field, and the authors found evidence of statistical associations between delayed language and reading skills in children and attendance, where schools were found to have higher outdoors noise levels. However, it is not known whether these observed small differences in test scores have a significant effect on subsequent development and academic progress. It is also not understood which features, if any, of the environmental noise measured outside the school are responsible for observed differences in test scores. Finally, the relative importance of exposure at higher levels outdoors versus exposure at lower levels from outdoor sources when indoors is not known. A lack of information on these areas and in particular on whether there are long-term effects has meant it is not possible to ascribe any economic valuation to the observed differences, and therefore this impact was not investigated in the second stage of the research.

79. A dose-response function found in the RANCH study[43] was put forward as the best available quantitative link. This study compared the effect of road traffic and aircraft noise on children's cognitive performance in the Netherlands, Spain and the UK. It found a linear exposure-response relationship between chronic aircraft noise exposure and impaired reading comprehension and recognition memory, after taking a range of socioeconomic and confounding factors into account.

80. In terms of the magnitude of the effect of aircraft noise on reading comprehension, a 5 dB(A) increase in aircraft noise exposure (expressed in LAeq, 16h) was associated with a 2-month delay in reading age in the UK and a 1-month delay in the Netherlands. The mean results for reading comprehension scores across all schools in all 3 countries are presented as Z-scores[44] in Figure 4. The 2-month reading delay corresponds to approximately 0.1 units on the Z-score scale.

Figure 4. Adjusted mean reading Z-score for 5 dB bands of aircraft noise (adjusted for age, sex, and country). 95% confidence intervals are shown.



IGCB response

81. The first IGCB(N) report separated the impacts of noise into four broad groups: health, amenity, productivity, and ecosystems. In keeping with this approach, the IGCB(N) believes that it is appropriate to present some impacts covered by this review as non-health impacts.

Annoyance

43 van Kempen, E. van Kamp, I. Fischer, P. Davies, H. Houthuijs, D. Stellato, R. Clark, C. & Stansfeld, S. (2006) "Noise Exposure and Children's Blood Pressure and Heart Rate: The RANCH Project", *Occupational and Environmental Medicine,* 63 (9) p632-639

44 "Z scores" are used to standardise results by transforming the range of available data points (i.e. the effect on reading age of schoolchildren) to fall within a range of -1 to 1, enabling comparison across noise levels (the mean is given by the circle at the centre of the upper and lower bounds of the data points for each noise range). Here, a value of zero indicates that there are no noise impacts on reading age; accordingly, where the mean value is negative, there is on average a delay in reading age associated with noise exposure at that particular decibel level.

82. Annoyance can be defined as the conscious feeling or state of being annoyed or irritated. Following this definition, and given the absence of robust evidence supporting the suggested adverse effect of annoyance on health, the IGCB(N) believes that annoyance should be classed as an **amenity**, rather than a health, impact.

83. Noise annoyance is defined by the World Health Organisation (WHO) as 'a feeling of displeasure evoked by noise'. Within government, the Department for Transport's WebTAG can be used for assessing the nuisance to people caused by road and rail traffic-related noise. These procedures have been developed from surveys of the impacts of noise from transport on people, including dissatisfaction, annoyance and disturbance. More recently, the Department for Transport commissioned hedonic pricing research to analyse differences in house prices for properties with different levels of exposure to transport-related noise, aimed at putting a monetary value on the annoyance impacts of noise. These values are now incorporated into the WebTAG guidance document for noise assessment[45].

84. WHO evidence suggests that around 15% of all Europeans suffer from "severe" annoyance as a result of noise[46]. This indicates that annoyance may constitute a significant proportion of the total cost of noise. In May 2007, a survey by the UK National Society for Clean Air showed that noise has a 'major impact' on 45% of respondents, compared with 35% a year earlier. Meanwhile, figures from the Office for National Statistics indicate that noise complaints to local authorities have more than doubled over the past decade.[47]

85. It is clear that noise can have an impact on annoyance; however, owing to the subjective nature of annoyance, the IGCB(N) has found no new research to provide a more robust empirical link. Therefore, the IGCB(N) continues to recommend the use of the Department for Transport's WebTAG in valuing changes in noise on amenity[48]. This guidance specifically values noise pollution from road and rail sources. In the absence of similar evidence for other noise sources, it is recommended that these values be applied to provide an indication of the level of detriment.

86. Annoyance impacts are already reflected in policy decisions through available evidence, such as WebTAG and public complaints about noise. Coupling this with the lack of progress in external evidence-gathering, the IGCB(N) does not consider that further research aimed at obtaining new economic values for annoyance impacts is a priority. However, given the potential importance of this impact, the IGCB(N) will continue to monitor potential opportunities to progress application of this area, for example, any work to refresh the 1999/2000 National Noise Attitude Survey[49].

[45] http://www.dft.gov.uk/webtag/documents/expert/pdf/unit3.3.2d.pdf
[46] http://www.euro.who.int/Noise/activities/20021203_3
[47] http://www.statistics.gov.uk/StatBase/ssdataset.asp?vlnk=7295&Pos=1&ColRank=1&Rank=272
[48] For more information, visit www.dft.gov.uk/webtag/.
[49] For more information, visit http://www.bre.co.uk/pdf/NAS.pdf

Self-reported sleep disturbance

87. Sleep disturbance has been shown to have notable negative impacts on both productivity and human health[50]. This creates a challenge in fitting this impact into the four broad groups of health, amenity, productivity and ecosystems. However, the health impacts are likely to be captured and quantified in focussed studies on health outcomes of noise exposure. Therefore, the IGCB(N) believes that any statistical link found between sleep disturbance and noise levels should primarily feed into the quantified impacts on **productivity**. The key link from sleep disturbance to productivity is seen to be fatigue ("next day sleepiness").

88. There is a large body of evidence to support the hypothesis that sleep disturbance leads to productivity losses and other fatigue-driven impacts, such as increased errors, reduced decision-making ability, absenteeism, stress, worsened work performance and increased accidents[51]. A 2009 Canadian study valued the impact of insomnia at CDN$6.6 billion, of which $970.6 million was attributed to insomnia-related absenteeism and $5 billion to insomnia-related productivity losses[52]. Other research in Australia has shown that sleep deprivation through sleep disorders such as insomnia cost AU$1,201 million in 2004 as a result of productivity losses (and this does not include the costs of work-related injuries associated with sleep disorders)[53].

89. WHO analysis suggests that around 2% of Europeans are severely sleep-disturbed as a result of noise.[54] This estimate suggests that the productivity effects outlined above could be affecting one in fifty people.

90. Therefore, and bearing in mind the uncertainties in these estimates, the IGCB(N) recommends the use of the EC dose-response functions for estimating low, medium and high sleep disturbances that can as a result be reflected in policy appraisal.

91. Despite the dose-response functions provided in the research on noise and sleep disturbances, it is not possible to value the impacts of change in noise on productivity losses (as the relationship between sleep disturbance and productivity is uncertain). This is seen as being a major gap in impact evaluation, particularly given the potential number of incidences of sleep disturbance. Therefore, the IGCB(N) considers this a priority research area and will scope further work aimed to quantify a link between sleep disturbance and productivity.

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[50] Belenky, G. Wesenten, N. Thorne, D. Thomas, M. Sing, H. Redmond, D. Russo, M. & Balkin, T (2003) "Patterns of performance degradation and restoration during sleep restriction and subsequent recovery: a sleep dose-response study", *Journal of Sleep Research*, Vol. 12, pp. 1-12

[51] Czeisler, C. & Fryer, B. (2006) "Sleep Deficit: The Performance Killer", *Harvard Business Review*

[52] Daley, M. Morin, C. LeBlanc, M. Grégoire, J-P. & Savard, J. (2009) "The Economic Burden of Insomnia: Direct and Indirect Costs for Individuals with Insomnia Syndrome, Insomnia Symptoms, and Good Sleepers", *SLEEP*, Vol. 32(1) pp. 55-64
http://www.journalsleep.org/ViewAbstract.aspx?pid=27327

[53] Hillman, D. et al. (2006) "The Economic Cost of Sleep Disorders", *SLEEP,* 29 (3) p. 299-305
http://www.journalsleep.org/Article/290305.pdf

[54] http://www.euro.who.int/Noise/activities/20021203_3

Cognitive effects on children

92. As with sleep disturbances, cognitive effects on children could be considered a health effect. However, the IGCB(N) considers this more as an impact on long-term **productivity**. Intuitively, it is felt that any reduction in cognitive development from noise may be seen to have a detrimental impact on the quality of the UK labour force and hence on productivity of the economy.

93. Some studies have successfully determined a statistical relationship between childhood intelligence and adult earnings. Studies investigating the neuro-developmental effects of mercury exposure on children used the Wechsler Intelligence Scale for Children-Revised Full-Scale IQ, and could determine how the IQ score changed with different concentrations of mercury. It was then possible to place a value on IQ points lost using results from another study which used average lifetime earnings to determine the monetary value of one IQ point.[55]

94. A similar methodology could be used in determining the effects of exposure to higher levels of environmental noise at an early age on academic achievement and adult productivity. However, this would require significant long term study of the research that is available. At that stage, it might then be necessary to revisit work which estimates how differences in IQ at a young age impact on scholastic attainment, and the subsequent impact of scholastic attainment on both wages and labour force participation. If a robust link is discovered, the research that determined a methodology for placing a value on one IQ point in terms of lifetime earnings (including the effects on labour force participation) could be accordingly modified to determine the overall social cost.

95. While productivity loss arising from cognitive effects on children is an important area for further consideration, it is not considered a key priority at this stage owing to the amount of additional research needed to formulate a workable methodology for policy appraisal.

[55] A demonstration of this methodology is provided in the consultation on UK implementation of enforcement obligations on ban of export of metallic mercury and certain metallic mercury compounds and mixtures, and the safe storage of metallic mercury.
www.defra.gov.uk/corporate/consult/mercury/index.htm

Chapter 5: Structural barriers

96. In addition to the literature review, this research proposed a range of structural barriers that have prevented or slowed agreement within the academic community on a single dose-response for any one of these impacts (thus also preventing the creation of a resultant methodology for policymakers to quantify and monetise the impacts of noise). This chapter outlines the structural barriers that were identified and the IGCB(N) responses to these challenges. However, most of the challenges identified appear beyond the remit of the IGCB(N) to address.

Structural barriers identified

97. Discussions with experts (including Irene van Kamp at RIVM and Wolfgang Babisch) that had been involved in WHO initiatives to produce globally agreed dose-response relationships formed the basis of the investigation. These discussions highlighted several possible structural barriers or non-scientific reasons for delayed progress in agreeing on the robustness of the latest research, which are given below:

- *Differences in basic methodology, including regression analyses.*
  Different approaches have been used by RIVM and by Babisch in their respective meta-analyses to assess estimates of effects when data are pooled and exposure-response relationships in order to carry out a quantitative risk assessment. RIVM calculate uniform regression coefficients across all noise categories within individual studies ('regression approach'). The regression coefficients are then pooled over all studies. Babisch calculates pooled relative risks for individual noise categories from different noise studies, which were then considered for an exposure-response relationship ('category approach'). Both approaches have advantages and disadvantages. However, because the two approaches were developed from different organisations, so far the differences have not been resolved. But we were informed that a joint paper is being prepared for the journal *“Noise & Health”* which will show the implications of using the different curves. It is not known as yet if the paper will propose some compromise, but this matter should be followed up.

- *Basic differences in “belief” about causality.*
  By “belief” in this context, we mean that experts in any field over many years tend to build up an “integrated view” of the underlying causes of the various factors that they are measuring, studying and discussing with other experts in the field. In this particular field, where many or even most of the individual research studies are inconclusive or subject to considerable uncertainty, and where contradictory and/or negative results are not unusual, it is likely that many experts, when put under pressure to come up with informed opinions, will tend towards forming overall judgements based on general trends and overviews and might possibly tend to place a little more weight on pieces of evidence that support their personal beliefs than on pieces of evidence that do not. Comparing Babisch with the experts at RIVM, it was clear that, even on the basis of largely the same evidence, RIVM tend to have a marginally more cautious view when interpreting the evidence, although they still make practical use of the observed relationships for health impact analysis. In general, and when looking through the various papers reviewed herein, it is clear that different authors often take a more or less cautious view when inferring the possibility of causal relationships from what is often statistically inconclusive or experimentally confounded data. It is perhaps unfortunate that

future research funding often depends on having obtained 'successful' or conclusive results in previous research, whereas in fact negative results (i.e. no relationship found) should be of equivalent value even though they often are not perceived as such.

- *Institutional inertia where methods already exist.*
  This is a normal situation which can apply to a range of issues in noise regulation and legislation. Within a given country, considerable effort may have been put into individual research projects and the reviewing of research outcomes leading to the development of local methods for assessing noise effects. Such methods are then embedded in legislative documents. In very few cases are mechanisms maintained on a long term basis for periodic review. To some extent the Netherlands is an exception to this, through its National Health Council. The proposal in the new HPA review report[56] for a standing committee would go some way to resolve this issue.

- *A bias towards methods based only on national research in a particular country.*
  Particularly where health issues are concerned, there is sometimes reluctance to "import" findings from other countries, with an innate and probably irrational belief that the population of one's own country is somehow unique, or that some of the factors potentially involved, for example the degree of industrialisation, mean that results from one country cannot be generalised to others. It might be argued that the WHO should provide a suitable forum for sharing information and hence resolving such issues, but this does not seem to have been the case so far. The setting up of a new EU-funded "European Research Network on Noise and Health" due to start in September 2009 might contribute to reducing such national bias.

- *Conflicting views of stakeholders.*
  In a complex topic such as this, it is inevitable that just as different researchers may have different views, so also may different stakeholders have different views on the level of evidence required as a justification for action. Industry, with a view to the major economic implications of any action will often take one view, whilst environmental groups will generally tend to take a more "precautionary" line.

IGCB response

98. The identification of these challenges to the estimation and valuation of noise impacts on health is extremely useful when considering long term progress in this area. The IGCB(N) believes that the recognition of such structural challenges is an important step towards addressing them and thereby supporting the development of more widespread and consistent use of dose-response functions internationally. Each of these barriers is discussed below:

[56] Health Protection Agency (2009), "Environmental Noise and Health in the UK"
http://www.hpa.org.uk/webw/HPAweb&Page&HPAwebAutoListName/Page/1246433632961

99. The first barrier relates to the difficulty in aligning studies owing to methodological differences. Such differences make consolidation of the literature increasingly challenging and hence create additional uncertainty and disagreement over the likely scale of the impacts. This barrier may arise from the understandable desire to test data and theories in a manner of different ways that is seen to deliver the most robust evidence. The decision to move to a single methodology would need to balance the benefits of comparability across studies with the potential costs in committing research to a single methodological approach, which could fail to be most desirable in generating robust results. Given its remit, the IGCB(N) does not have the expertise to recommend an international methodology for noise impact research. However, such a role could be undertaken any group of experts in this area (such as the Department of Health Ad Hoc Expert Group on Noise).

100. Institutional inertia is based on the external perception that there is a notable delay between the publication of new research and its being reflected in policy decisions. The apparent delay is in fact a reflection of the time and challenge in reviewing and balancing new evidence, a consideration that is difficult for external groups to appreciate. For example, the Babisch curve has been the subject of notable debate since its publication in 2006, and only now does the IGCB(N) believe that the consensus of approval from the academic world is strong enough to incorporate this evidence into evaluation methodology. It should be noted that the IGCB(N) hopes to help reduce these delays through its publications (such as this one), which explicitly link the development of evidence with policy needs.

101. It was felt that national policy appraisal development places unduly high weighting on domestic evidence at the expense of considering valuable external studies in formulating evaluation methodologies. The IGCB(N) does not exclude evidence from other geographic areas; however, it is true that additional weight may be given to national studies. The key reason for this is that as noise is subjective, national studies are seen to better reflect uniquely national characteristics of the domestic population's sensitivities and susceptibilities to noise. However, the IGCB(N) continues to monitor international evidence, and welcomes the formation of the European Network on Noise and Health (ENNAH)[57], which will facilitate this work. At the present time, the IGCB(N) is considering how best it could contribute to this group.

102. Finally, different stakeholders may require different levels of evidence before accepting the need for policy intervention. Given the differing interests and incentives of the wide range of stakeholders, this divergence in the demand for proof is understandable. Again, tackling this barrier by reconciling the different burdens of proof demanded is seen to be outside the expertise and remit of the IGCB(N). It is suggested that, again, an external group of experts could offer useful insights in balancing the merits of the different evidence and providing advice on the best available evidence.

[57] For more information, visit www.ennah.eu.

Chapter 6: Conclusions and ongoing work of the IGCB(N)

103. There is growing evidence linking noise and a range of adverse impacts on, for example, human health, public amenity, economic performance (through productivity) and local ecosystems. However, at present many of these impacts are not reflected in the current economic valuation of noise pollution, which is based on hedonic pricing analysis and focuses on conscious annoyance, or "amenity", impacts.

104. To address this gap, the Interdepartmental Group on Costs and Benefits noise subject group (IGCB(N)) was formed, with the aim of developing and disseminating robust economic approaches for appraisal of noise. The first publication of this group identified the impact pathway approach as the relevant methodological framework for quantifying and monetising the impacts of noise. The next step was to start to identify the relevant links by which noise impacts on the public. The priority area considered for further investigation was the links between noise and health impacts. Experts Bernard Berry and Dr Ian Flindell were commissioned to undertake a review of research into these links between noise and health, and identify those impacts with a sufficiently robust evidence base to be incorporated into the IGCB(N) methodology.

105. This research surveyed the existing literature and found important evidence linking noise and health impacts, such as annoyance, mental health, cardiovascular and physiological impacts (including acute myocardial infarction and hypertension), hearing impairment, night-time effects (such as increased sleep disturbances, reduced sleep quality and worsened next-day work performance), and worsened academic performance by schoolchildren.

106. The research also identified a wide range of areas that required further research, which included fundamental research on definitions (such as sleep disturbance), reviewing existing links (including the meta-analysis on hypertension), considering confounding factors (such as air quality and self-selection bias) and practical challenges (including reflecting differing impacts across noise sources).

107. In spite of the inherent uncertainties and sensitivities around these dose-response functions, in line with the "precautionary principle", their use is recommended as the current gap in appraisal in valuing these noise impacts is potentially leading to greater risks through the delayed abatement of these health effects. In order to address concerns around the accuracy of the methodology, Berry and Flindell required dose-response functions to have a relatively high level of robustness in comparison to other studies used in government appraisal. However, policymakers using these evaluation tools should bear in mind limitations in the methodology, notably the confounding factors of air quality and self-section bias. Given the expanding literature on noise and health, the IGCB(N) will actively monitor developments in research in order to address these uncertainties and reflect the latest developments in identification and quantification of impacts to improve the valuation of noise.

108. The IGCB(N) has grouped its responses to the noise and health review conducted by Berry and Flindell into three areas, given the varying levels of evidence linking each impact studied to noise. The responses are summarised below:

(i) Immediate action can be taken where links have been shown and strong quantitative links exist:

- Amenity impacts should continue to be used in policy appraisal of noise. Values should be taken from Department for Transport's WebTAG guidance (www.dft.gov.uk/webtag/).

- Acute myocardial infarction (AMI) can be applied into monetary valuation of noise using the 2006 Babisch dose-response function. Including this health impact will be a major step forward in the valuation of road traffic and industrial noise. Accordingly, the IGCB(N) is recommending the use of the Babisch curve to assess the additional risk of AMI with rising noise levels and has generated a methodology which monetises this risk (see Annex A of this document). However, policymakers using this methodology must be mindful of the uncertainties previously highlighted.

- Hypertension is identified as a notable impact of changes in noise levels. Evidence on this area is developing rapidly but it is not currently sufficient to value this impact in monetary terms. The IGCB(N) therefore recommends that indicative values on the incidence of hypertension be included in appraisal based on the 2009 Babisch and van Kamp dose-response function. The approach to using this function is provided in Annex B of this document.

- Self-reported sleep disturbance is seen to have a clear link to the levels of noise; however, again, it is not possible to value these impacts. To reflect this, the IGCB(N) recommends the use of the dose-response functions highlighted in 2004 EC position paper in appraisal to illustrate the scale of the impacts. The approach to estimating these changes is provided in Annex C.

- A robust methodology already exists in relation to hearing impairment. Therefore the IGCB(N) recommends that the HSE's ISO 1990:1999 standard methodology be used in the rare circumstances where noise reaches the relevant level (above 75 dB).

(ii) This research also identified a wide range of gaps and hence potential research areas of interest in the prevailing knowledge. Immediate priorities identified by the IGCB(N) are:

- Identifying the health outcomes of hypertension, and reviewing the approaches to value these impacts in monetary terms.

- Research considering the impacts of sleep disturbance such as on next-day productivity and amenity. Such work would enable a monetary value to be placed on the sleep impacts of noise.

- Notable developments in the approach to valuing ecosystems through the Ecosystem Services Approach (ESA) could help to facilitate the assessment and inclusion of such impacts into appraisal.

(iii) Some areas identified required continued consideration over the medium term:

- Until new evidence linking noise to mental health and cognitive development in children arises, further research has been deemed unnecessary.

- New evidence was identified surrounding annoyance impacts but was not robust enough to warrant change in the way this impact was appraised. However, it appears that amenity costs may potentially be very large, justifying additional research should the evidence become available.

109. Finally, a range of structural barriers were identified in order to explain the challenges to the development of global appraisal approaches to environmental noise i.e. the development of a single dose-response function for any of these impacts. These challenges include methodological differences between studies preventing comparability, the use of subjective judgments by experts, varying demands surrounding burden of proof, the institutional inertia associated with the revision of existing approaches, and national biases preventing the use of external research.

110. The IGCB(N) recognises the identification of these barriers as a notable contribution to addressing them. However many of these areas require changes that are outside the remit of the IGCB(N). In such instances, the IGBC(N) feed into considerations of approaches to address these challenges. For example it will input into discussions to establish a standing group on the health effects of noise.

Annex A: Methodology to estimate and value acute myocardial infarction

A.1 A key recommendation of the research is that the dose-response relationship proposed by Babisch (2006) provides an adequate basis from which to value health effects. This is a major step in enabling health impacts to be valued; however, this methodology for valuation requires a range of assumptions, which represent a pragmatic approach to developing values. There are inherent uncertainties in deriving these impacts, which should be reflected in any use of this methodology. However, while the estimates are uncertain, the justification for using them is that it is felt that it would be more misleading to not provide any values.

A.2 This annex provides an overview of the methodology that was applied to estimate and value the marginal health costs of acute myocardial infarctions (AMI). The methodology follows the general impact pathway approach adopted by the IGCB(N), linking exposure to noise pollution to the associated health outcome that is then valued monetarily.

A.3 In keeping with existing approaches to the evaluation of noise across policy options, it was decided to estimate marginal values per decibel and per household affected. The advantage of producing marginal figures is that they then can be applied across a wide range of policy decisions. This design choice also reflects the way that noise is currently reflected in policy appraisal and so minimises any additional burden in use.

A.4 The calculation of marginal impact values involves two simple steps: firstly, calculating the change in the risk of incidences of AMI, and second, valuing the expected changes using a given social cost of a single incidence of AMI. When applied in a particular policy appraisal, the marginal value is multiplied by the number of households affected by that policy to calculate the total impact. Hence, the methodology does not attempt to reflect the associated levels of exposure with any particular policy.

A.5 The remainder of the annex explains how the three variables necessary to construct the dose-response function were calculated:

- Estimation of changes in numbers of incidents of AMI in response to changes in noise levels;
- Valuation of incidences of AMI; and
- Results provided per dB above 55 dB(A).

Changes in the risk of AMI

A.6 The dose-response relationship proposed by Babish (2006) provides a clear unique quantitative link between the levels of noise and the increased relative risk of AMI above a baseline noise level of 55 dB. The quantitative results produced from this can be valued to derive marginal costs for each rising decibel of noise.

A.7 Babisch uses Lday 16hr as the measure of noise in his dose-response function, while current appraisal methodology tends to require the estimation of noise measures using LAeq 18hr dB(A). The key difference between these two measures is that that Lday covers a 16-hour period while the LAeq 18hr averages noise over an 18-hour period.

A.8 Despite these differences, these two measures are highly correlated. Therefore, this methodology has assumed equivalency between them. However, wherever information is available providing both measures, the LAeq 18hr values should be applied in preference to assuming equivalency.

A.9 The odds ratio (OR) estimated by the Babisch function is used to estimate the changes in relative risk of AMI above a baseline environmental noise level. In order to estimate the exact increase in the probability of AMI at any noise level, it is necessary to know the average prevailing probability.

A.10 Estimation of the average probability of AMI is based on 2006 London data, recording 6,313 cases across the population of 7.5 million[58]. From this data, the average probability of AMI has been estimated at 0.0084% (i.e. around 1 in 12,000 persons).

A.11 These changes in risk are applied per household exposed to the change in noise, so it is necessary to estimate the associated level of exposure by equating the exposed population to the number of households. The 2001 census places the population of England at 49 million people, with a housing stock of 20 million. Based on a straightforward calculation of the mean, it has been assumed that each household has on average a residential population of 2.4 people.

A.12 Therefore, by multiplying the change in the OR by the prevailing probability and the level of exposure, it is possible to estimate the increased risk of AMI from an increase in noise levels. Column 3 of Table 2 presents the additional risk of AMI resulting from each 1 dB rise in environmental noise. For example, increasing noise levels from 69 dB(A) to 70 dB(A) increases the risk of AMI by 0.0038%.

Valuation of AMI

A.13 Once the change in the risk of AMI has been estimated, it is necessary to value this change using an associated cost. The cost of AMI could be said to include the impacts on the sufferer, impacts on relatives of the sufferer and impacts on wider society (such as any knock-on effects on productivity). As this analysis only reflects the direct impact on the sufferer of AMI, the value may be considered an underestimate of the full social cost.

A.14 The severity of AMI can widely vary, from immediate premature death for some sufferers to a full recovery for others. To reflect this range of outcomes in this methodology, the impacts of AMI have been divided into two groups: incidents that lead to immediate death (mortality) and incidents that do not (morbidity). Evidence presented in the research shows that around 72% of AMI would fall into the former group, with 28% in the latter.

A.15 In valuing these health outcomes, it is necessary to know both the number of years of life lost or diminished in quality as a result of AMI and the monetary value of each of those years. Both of these are subject to notable uncertainty.

A.16 For both mortality and morbidity, it has been assumed that AMI reduces life expectancy by eleven years. This value is based on average life expectancy following an incidence based on ONS data[59].

[58] Sources of data provided on page 147 of the technical report.

A.17 The value of one life-year in full health is set at £60,000 in accordance with the central estimate value of a QALY, applied across Whitehall. There are, however, a wide range of alternate life-year values currently in use, ranging from the £29,000 used by the IGCB air quality subject group to the £130,000 applied in some areas of the Health and Safety Executive. The £60,000 figure has been selected to provide a defensible compromise, but may be revised in light of the findings of the Interdepartmental Group on the Value of Life and Health (IGVLH).

A.18 Finally, the disability weighting for individuals who have suffered an AMI has been set at 0.405, in line with WHO guidance[60]. Hence, the value placed on a life-year after suffering an AMI is 40.5% of the value of a life-year in good health, or £24,300.

A.19 These newly-derived health values, alongside the current values (which reflect only amenity impacts), are shown in Table 2 below:

[59] http://www.statistics.gov.uk/STATBASE/

[60] World Health Organisation (2004) "Global Burdens of Disease 2004 Update: Disability Weights for Diseases and Conditions"
http://www.who.int/healthinfo/global_burden_disease/GBD2004_DisabilityWeights.pdf

Table 2: Valuation of AMI impacts of noise

Volume ($L_{Aeq,\ 18hr}$ dB(A))		Additional risk of AMI	£ per household per dB change		
Low	High		Health value	Amenity/annoyance value [a]	Total
55	56	0.00000%	£0.00	£34.80	£34.80
56	57	0.00000%	£0.48	£37.40	£37.88
57	58	0.00010%	£2.70	£40.00	£42.70
58	59	0.00048%	£4.16	£42.70	£46.86
59	60	0.00072%	£5.67	£45.30	£50.97
60	61	0.00096%	£7.22	£48.00	£55.22
61	62	0.00144%	£8.82	£50.60	£59.42
62	63	0.00168%	£10.47	£53.20	£63.67
63	64	0.00192%	£12.17	£55.90	£68.07
64	65	0.00216%	£13.92	£58.50	£72.42
65	66	0.00264%	£15.71	£61.10	£76.81
66	67	0.00288%	£17.56	£63.80	£81.36
67	68	0.00336%	£19.45	£66.40	£85.85
68	69	0.00360%	£21.39	£69.00	£90.39
69	70	0.00384%	£23.37	£71.70	£95.07
70	71	0.00432%	£25.41	£74.30	£99.71
71	72	0.00480%	£27.49	£76.90	£104.39
72	73	0.00504%	£29.62	£79.60	£109.22
73	74	0.00552%	£31.81	£82.20	£114.01
`74	75	0.00576%	£34.03	£84.90	£118.93
75	76	0.00624%	£36.31	£87.50	£123.81
76	77	0.00672%	£38.64	£90.10	£128.74
77	78	0.00720%	£41.01	£92.80	£133.81
78	79	0.00768%	£43.43	£95.40	£138.83
79	80	0.00792%	£45.90	£98.00	£143.90
80	81	0.00840%	£48.42	£98.00	£146.42

[a] WebTAG values www.dft.gov.uk/webtag/

Annex B: Estimation of the link between noise and hypertension

B.1 A recommendation of the research is that the dose-response relationship proposed by Babisch and van Kamp (2009)[61] be used to quantify the links between noise and hypertension until more data becomes available. Inclusion of this health impact into the IGCB(N) methodology is an important step as it is currently not possible to value these outcomes. Estimating the number of incidences requires a range of additional assumptions to allow the pragmatic reflection of this evidence. It must be stressed that there remain inherent uncertainties in deriving these impacts which should be reflected in any use of this methodology. However, while these estimates are uncertain, the justification for using them is that it is felt that it would be more misleading not to provide any estimates.

B.2 This annex provides an overview of the methodology that was applied to estimate the impacts of noise on incidences of hypertension. The methodology follows the general impact pathway approach adopted by the IGCB(N), linking exposure to noise pollution with the associated health outcome. In this case, the health outcome (hypertension) is not valued as this is not possible using the available evidence.

B.3 In keeping with existing approaches to the appraisal of noise across policy options, it was decided to estimate marginal values per decibel and per household affected. The advantage of producing marginal figures is that they then can be applied across a wide range of policy decisions. This design choice also reflects the way that noise is currently reflected in policy appraisal and so minimises any additional burden in use.

B.4 The calculation of marginal impact values involves using the identified dose-response function to calculate the change in the risk of incidences of hypertension arising from a given change in noise levels. When applied in a particular policy appraisal, this marginal value is multiplied by the number of households affected by that policy to calculate the total impact. Hence, the methodology does not attempt to reflect the associated levels of exposure with any particular decision.

Changes in the risk of hypertension

B.5 The dose-response relationship proposed by Babisch and van Kamp (2009) provides a clear and unique quantitative link between the levels of noise and the increased relative risk of hypertension above a baseline noise level of 55 dB. This paper uses Lden as the measure of noise in this dose-response function, while current appraisal methodology tends to require the estimation of noise measures using LAeq 18hr dB(A). The key difference between these two measures is that that Lden is an indicator of the overall noise level during the day, evening and night while the LAeq 18hr averages noise over an 18-hour period.

B.6 Despite these differences, these two measures are highly correlated. Therefore, this methodology has assumed equivalency between them. However, wherever information is available providing both measures, the Lden values should be applied in preference to assuming equivalency.

[61] Babisch, W. & van Kamp, I. (2009) "Exposure-response relationship of the association between aircraft noise and the risk of hypertension", *Noise & Health*, 11 (4) p. 161-168
http://www.noiseandhealth.org/article.asp?issn=1463-1741;year=2009;volume=11;issue=44;spage=161;epage=168;aulast=Babisch;type=0

B.7 The odds ratio (OR) estimated by the function is used to estimate the changes in relative risk of hypertension above a baseline environmental noise level. In order to estimate the exact increase in the probability of hypertension at any noise level, it is necessary to know the average prevailing probability.

B.8 The population treated for hypertension has been used as a proxy for the prevailing rate of hypertension. The Health Survey for England (2006)[62] found that in 2006, 54% of the population had been treated for hypertension. Treatment was, however, seen to be significantly higher for women (62%) than for men (47%).

B.9 This prevailing risk can be multiplied by the change in the OR; it is then possible to estimate the increased risk of hypertension from an increase in noise levels.

B.10 This report identified a linear relationship between noise and hypertension with a relative risk of 1.13 (i.e. a 13% increase in the risk of hypertension above the level of risk at the baseline) for each 10 dB(A) increase in Lden, above a baseline of 55 dB(A).

B.11 In keeping with existing evaluation methodology, this change in probability for each individual is scaled up to each household in order to provide a change per household measure. These changes in risk are applied per household exposed to the change in noise, so it is necessary to estimate the associated level of exposure by equating the exposed population to the number of households. The 2001 Census places the population of England at 49 million people, with a housing stock of 20 million. Based on a straightforward calculation of the mean, it has been assumed that each household has on average a residential population of 2.4 people.

B.12 Based on these values, it is recommended that:

For each 1 dB(A) Lden increase in noise exposure per household above 55 dB, there is an expected increase in hypertension of 0.01594. Over 1,000 houses, this equates to 16 new cases of hypertension.

[62] The In3formation Centre, NHS (2006) "Health Survey for England 2006: Cardiovascular disease (CVD) and risk factors adults, obesity and risk factors children"
http://www.ic.nhs.uk/pubs/hse06cvdandriskfactors

Annex C: Polynomial functions approximating indicative dose-response functions between noise levels and self-reported sleep disturbance

B.1 A recommendation of the research is that the polynomial functions approximating dose-response relationships proposed by the 2004 EC position paper[63] be used to quantify the links between noise and sleep disturbance until more data becomes available. Inclusion of this health impact into the IGCB(N) methodology is an important step as it is currently not possible to value these outcomes. Estimating the number of incidences requires a range of additional assumptions to allow the pragmatic reflection of this evidence. It must be stressed that there remain inherent uncertainties in deriving these impacts which should be reflected in any use of this methodology. However, while these estimates are uncertain, the justification for using them is that it is felt that it would be more misleading not to provide any estimates.

B.2 This annex provides an overview of the methodology that was applied to estimate the impacts of noise on incidences of sleep disturbance. The methodology is based on surveys conducted in the Netherlands in 1998 and 2003, and the scale of magnitude of its findings is consistent with UK studies of annoyance from noise-induced sleep disturbance. As with the impact pathway approach, this methodology links exposure to noise pollution with the associated health outcome. In this case, the health outcome (sleep disturbance) is not valued as this is not possible using the available evidence.

B.3 In keeping with existing approaches to the evaluation of noise across policy options, it was decided to estimate marginal values per decibel and per household affected. The advantage of producing marginal figures is that they then can be applied across a wide range of policy decisions. This design choice also reflects the way that noise is currently reflected in policy appraisal and so minimises any additional burden in use.

B.4 The calculation of marginal impact values involves using the identified polynomial functions to calculate the change in the risk of incidences of sleep disturbance arising from a given change in noise levels. When applied in policy appraisal for a particular transport mode, this marginal value is multiplied by the number of households affected by that policy to calculate the total impact. Hence, the methodology does not attempt to reflect noise exposure associated with any particular decision.

Changes in the risk of sleep disturbance

B.5 The polynomial functions proposed by the EC (2004) provide clear and unique quantitative links between the levels of noise and the increased relative risk of varying levels of sleep disturbance above a chosen baseline noise level. This paper uses Lnight as the measure of noise in its polynomial functions, while current appraisal methodologies tend to require the estimation of noise measures using LAeq 18hr dB(A). The key difference between these two measures is that Lnight is an indicator of the overall noise level during night-time while LAeq 18hr averages noise over an 18-hour period.

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[63] European Commission Working Group on Health and Socio-Economic Aspects of Noise (2004) "Position paper on dose-effect relationships for night-time noise."
http://ec.europa.eu/environment/noise/pdf/positionpaper.pdf

B.6 Though these two metrics are correlated, as yet, no equivalency adjustment between has been calculated. Therefore, this methodology has assumed equivalency between them. The IGCB(N) is seeking some means of approximately converting LAeq 18hr to Lnight; in the meantime, wherever information is available providing both measures, the Lnight values should be applied in preference to assuming equivalency.

B.7 This report identified quadratic relationships between noise and self-reported sleep disturbance with risks of Low, Moderate and High sleep disturbance rising with each dB(A) increase in Lnight. These transport-specific polynomial functions are used to estimate the risk of a given level of self-reported sleep disturbance at a chosen night-time decibel level.

B.8 The polynomial functions were derived from surveys conducted in the Netherlands in 1998 and 2003 in which 4000 and 2000 people respectively, all of whom were randomly selected, were asked: "To what extent is your sleep disturbed by noise from [source]...." on a scale from 1 to 10. People recording the 3 highest points in the scale were considered "highly disturbed", following the international convention.

B.9 In keeping with existing evaluation methodology, this change in probability for each individual is scaled up to each household in order to provide a change per household measure. These changes in risk are applied per household exposed to the change in noise, so it is necessary to estimate the associated level of exposure by equating the exposed population to the number of households. The 2001 Census places the population of England at 49 million people, with a housing stock of 20 million. Based on a straightforward calculation of the mean, it has been assumed that each household has on average a residential population of 2.4 people.

B.10 The formulae of these polynomial approximations are provided below:

- %HSD = percentage of individuals with High Sleep Disturbance
- %SD = percentage of individuals with Moderate Sleep Disturbance
- %LSD = percentage of individuals with Low Sleep Disturbance

B.11 For road traffic noise:

- $\%HSD = 20.8 - 1.05L_{night} + 0.01486(L_{night})^2$
- $\%SD = 13.8 - 0.85L_{night} + 0.01670(L_{night})^2$
- $\%LSD = -8.4 + 0.16L_{night} + 0.01081(L_{night})^2$

B.12 For railway noise:

- $\%HSD = 11.3 - 0.55L_{night} + 0.00759(L_{night})^2$
- $\%SD = 12.5 - 0.66L_{night} + 0.01121(L_{night})^2$
- $\%LSD = 4.7 - 0.31L_{night} + 0.01125(L_{night})^2$

B.13 For aircraft noise:

- $\%HSD = 18.174 - 0.956L_{night} + 0.01482(L_{night})^2$
- $\%SD = 13.714 - 0.807L_{night} + 0.01555(L_{night})^2$
- $\%LSD = 4.465 - 0.411L_{night} + 0.01395(L_{night})^2$

B.14 In order to calculate the marginal impacts of a policy which will affect night-time noise levels, the above polynomial functions can be used. Ensuring that the correct polynomial function for the mode of transport is used, the calculation is as follows:

(i) For each level of sleep disturbance (i.e. High, Moderate or Low), use Excel to input into the relevant polynomial equation the estimated Lnight (night-time decibel level) when the policy is in place to give equation (a). This will give the percentage risk factor for sleep disturbance when the policy is in place.

(ii) For each level of sleep disturbance (i.e. High, Moderate or Low), use Excel to input into the polynomial equation the Lnight (night-time decibel level) in the absence of the policy to give equation (b). This will give the baseline percentage risk factor for sleep disturbance.

(iii) The additional percentage risk of sleep disturbance to an individual at a particular level of disturbance arising from the introduction of the policy = (a) – (b).

(iv) Multiply this value by 2.4 to generate the number of *households* which will experience additional sleep disturbance at that given level of disturbance (assuming 2.4 individuals per household).

(v) Multiply this additional percentage risk factor by the total number of households estimated to be affected by the policy to generate the number of households which will experience additional sleep disturbance at that given level of disturbance.

(vi) Repeat this process using the relevant polynomial equations to calculate the additional number of households experiencing sleep disturbance at High, Moderate and Low sleep disturbance levels.

B.15 Worked example: Additional number of households experiencing Moderate sleep disturbance for a rail policy where night-time noise levels rise from 70 dB to 71 dB for 1,000 households:

(i) Equation (a) = $12.5 – (0.66*71) + 0.01121*(71)^2 = 22.15\%$

(ii) Equation (b) = $12.5 – (0.66*70) + 0.01121*(70)^2 = 21.23\%$

(iii) (a) – (b) = 26.06 – 21.23 = 0.92%

(iv) 0.92%*2.4 = 2.208%

(v) Additional number of households experiencing Moderate sleep disturbance = 2.208%*1000 households = 22.08 = 22 households

Annex D: Glossary of terms

A-weighted decibel (dB(A)): A unit of sound pressure level, adjusted in accordance with the A weighting scale, which takes into account the increased sensitivity of the human ear at higher frequencies.

Dose-response relationship: This is the statistical relationship defined between the value of the noise indicator (e.g. LAeq) and the impact studied (e.g. acute myocardial infarction).

Exposure: Is used to measure the amount of the pollutant (e.g. noise) experienced by a receptor (e.g. population). This term is used interchangeably with "dose" throughout in linking exposure to health effects.

LAeq, Th: The notional A-weighted equivalent continuous average sound level. The T denotes the time period over which the average is taken, for example LAeq, 8h is the A-weighted equivalent continuous noise level over an 8-hour period.

LAeq, 16h: The A-weighted average sound level over the 16-hour period of 0700-2300 hours.

Lday: The A-weighted average sound level over the 12-hour day period of 0700-1900 hours.

Levening: The A-weighted average sound level over the 4-hour evening period of 1900-2300 hours.

Lnight: The A-weighted average sound level over the 8-hour night period of 2300-0700 hours.

Lden: The day-evening-night level, Lden is a logarithmic composite of the Lday, Levening, and Lnight levels but with 5 dB(A) added to the Levening value and 10 dB(A) added to the Lnight value to account for increased residential population exposure during those periods.

Odds ratio: This describes the risk of an event relative to the risk inherent to another event. For example, an odds ratio of 1.15 of an incidence of acute myocardial infarction at 70 dB(A) relative to a baseline of 55 dB(A) indicates that the risk of acute myocardial infarction is 15% greater at environmental noise levels of 70 dB(A) than the level of risk at 55 dB(A).

Risk curve: The risk curve plots the changing levels of risk of an event (e.g. acute myocardial infarction) as noise levels rise above a baseline noise level, at which the risk of the event is set at 1. This facilitates understanding of relative risk given marginal changes in the variable studied (i.e. noise).

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Annex F: List of IGCB members

The member organisations of the Interdepartmental Group on Costs and Benefits are:

- Department for Environment, Food and Rural Affairs (Defra)
- Better Regulation Executive (BRE)
- Cabinet Office
- Department for Communities and Local Government (DCLG)
- Department for Transport (DfT)
- Department for Business Innovation and Skills (BIS)
- Department of Environment for Northern Ireland (DOENI)
- Department of Health (DH)
- Department of Energy and Climate Change (DECC)
- Environment Agency for England and Wales (EA)
- Foreign and Commonwealth Office (FCO)
- Health Protection Agency (HPA)
- Highways Agency
- HM Revenue & Customs (HMRC)
- HM Treasury
- Home Office
- National Assembly for Wales
- Scottish Environment Protection Agency (SEPA)
- Scottish Government